Transform Weather for Cycling

Solutions for thermally comfortable cycling

David FM Huijben

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A thesis submitted In partial fulfilment of the requirements for the degree of:

Master of Science (MSc) in Landscape Architecture

At the Wageningen University

By David F.M. Huijben

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Preface

Cycling to the campus and back home during my study of Landscape Architecture made me realize that weather is not always as nice as it looks like. Especially foreign students are not calculated to sudden hard winds, heavy rain and too high or low temperatures. Dutch people also tend to complain about the weather as an excuse for not using the bike. This is a pity because cycling improves people's health very well. I took the opportunity to alleviate these annoyances by trying to find solutions. While trying to find solutions, I discovered that the existing problem worsens due to climate change. The choice for the exploration of these weather problems is related to the intriguing complexity of designing fitting solutions for these uncomfortable conditions. The goal of this thesis is to improve people's health by (mainly) preventing Non-Communicable Diseases and promoting a healthier lifestyle. I intend to utilize the knowledge found in my thesis for my further career as a landscape architect and I hope that others also can enjoy the results of this thesis.

I have enjoyed working on my thesis and experienced this thesis as interesting, complex and as enlightening. Therefore, I want to thank Sanda Lenzholzer for her motivational and on-point supervision. I would also like to thank João Cortesão, the students of the Climatelier and other students of landscape architecture at the Gaia building, for their valuable input during my green light presentation and final report, motivation and sociability. I would like to thank Adri van den Brink for his input and opinion during my proposal presentation. Finally I would like to show my gratitude towards Karin de Graaf and my family for their support during the process of this thesis.

David Huijben, January 2017

Summary

Nowadays many people suffer from diseases worldwide, in Europe the Non-Communicable Diseases (NCDs) are the leading cause of death and disability. They have an increasing strain on health systems and well-being. Not only health is affected by these unhealthy lifestyles, but economic development as well. Active modes of transportation could be the solution for this unhealthy lifestyle. Especially the Netherlands provides the opportunity to improve people's health and lifestyle, because 28% of the people already use the bicycle regularly. However, people tend not to use the bicycle during uncomfortable weather conditions such as too warm weather (temperatures higher than 24 C°), too cold weather (temperatures under 15 C°) and precipitation. Thereby does climate change worsen the already existing problem of less people using the bike during uncomfortable weather conditions. This thesis searches for solutions which can improve the thermal perception of cyclists during uncomfortable weather situations, for the city of Rotterdam. The Research for Design (RFD) shows that internal physical- and physiological-, external physical- and psychological factors influence the thermal perception of cyclists. This thesis found that these influences are the worst on certain spatial problematic configurations/test beds; crossings, west – east routes, southwest routes, waterfront routes and open routes. Separate solutions for wind, shortwave radiation and precipitation are synthesized for these test beds. The RTD method is used for finding new solutions and evaluating them on an equal base by using criteria. The criteria are subject to the most important elements of the RFD phase. The separate solutions of wind, shortwave radiation and precipitation are combined into integrated solutions, which form the second iteration of the RTD method. The best scoring (integrated) solutions improve the thermal perception of cyclists during uncomfortable weather situations for every test bed. These solutions are flexible in use and able to transform their appearance according to the weather situation at that time. The designs are implemented in existing situations of Rotterdam in order to provide a realistic research product.

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Introduction

1. Research context

1.1 Goal of this thesis

Nowadays many people suffer from diseases worldwide, in Europe the Non-Communicable Diseases (NCDs) are the leading cause of death and disability. The four main types of NCDs are cardiovascular diseases, cancers, chronic respiratory diseases and diabetes. NCDs are also known as chronic diseases and are not passed from person to person. The diseases are mostly for a longer duration and generally have slow progression. In Europe, **NCDs account for nearly 86% of deaths** and 77% of the disease burden, putting increasing strain on health systems and the well-being of large parts of the population, in particular people aged 50 years and older (WHO, 2012). These NCDs are caused for example by the unhealthy lifestyles of people (tobacco use, physical inactivity, unhealthy diet and harmful use of alcohol) and the environment where we live in (Lim et al., 2012; WHO, 2012).
Not only health is affected by these unhealthy lifestyles, but economic development as well. Employers, and society as a whole, bear the burden of absenteeism, reduced productivity and increased employee turnover (WHO, 2012).**This thesis tries to improve this economic burden and people's health by (mainly) preventing NCDs and promoting a healthier lifestyle.**

1.2 Opportunity

Physical activity is influenced by urban environments and transport policies, which can promote cycling and walking for transport by developing safe infrastructure, as well as fostering the establishment of accessible green spaces for leisure-time physical activity and encouraging behaviour modification (WHO, 2012). Its proven that **picking active modes of transport** helps people for their overall fitness, has moderate benefits in cardiovascular risk factors, reduces all-cause mortality, coronary heart disease morbidity and mortality and reduces cancer risk, being overweight and obese (Oja, 2011; Panis, 2011; WHO, 2003). Active modes of transport are walking and especially in the Netherlands, cycling (Böcker, 2014). 28% of the total movements per person per day are done by bicycle in the Netherlands (CBS, 2014). This offers possibilities to tackle the problem of physical inactivity and thus increase people's health by designing comfortable environments to cycle through.

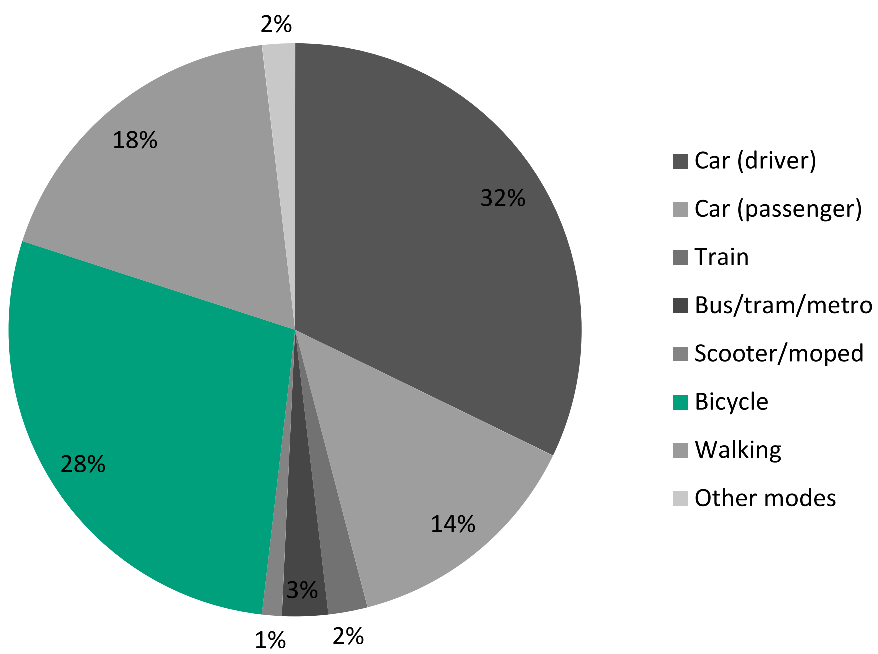


Figure 1.1: 28% of the people choose the bicycle as transport mode in the Netherlands (CBS, 2014)

1.3 Problem statement

Unfortunately many reasons occur for not using the bicycle. Weather is one of the main reasons. Bicyclist and other people who choose for an active mode of transport, do not have protection against the wind, cold (below 15 °C), precipitation (e.g. snow, rain or hail) and too hot weather conditions (above 24 °C). These conditions (in this thesis called 'uncomfortable weather conditions') have a negative effect on using active modes of transport (Böcker, 2014) and therefore are not helping to improve the human health (Oja, 2011; Panis, 2011; WHO, 2003).

In addition the climate is changing, which comes down to global temperature rise, changes in precipitation patterns and increased frequencies of extreme weather phenomena (IPCC, 2007). The temperature in the Netherlands will continue to rise, foremost in winter, which means less cold days will occur. The number of warm summer days increases, as the likelihood of heat waves. The temperature differences between coast and the inland will differ in summer and are less in winter. The total sum of precipitation will increase further and the likelihood of extreme rain showers with thunderstorms and hail will increase. Possible is a decrease in the total sum of precipitation during summer, but with frequent heavy rain showers (GH and WH scenarios). Wind patterns stay more or less the same as they are now. Solar radiation has slightly increased during the last decades, partly due the reduction in air pollution (KNMI, 2015).
The problem of receiving more solar radiation is worsened by the Urban Heat Island (UHI) effect. This is the effect where the city is warmer than the surrounding areas during warmer days. Inner cities trap incoming shortwave radiation in their built environment and emit stored radiation in the form of longwave radiation during the night to the early morning (during days with high temperatures). This phenomenon where more radiation is trapped during the day and emitted during the night could have temperature differences up to 10 C° compared with the rural areas around the cities (Lenzholzer, 2013). Figure 1.2 shows how long this effect could last during warmer days in Rotterdam, when the 2050 W+ scenario is used. The assigned problem routes are mainly located in the most problematic area of the UHI effect. This means (not all of) the warmth of the previous day(s) is lost during the night and makes the probability of temperatures above 24 C° larger, which negatively effects cycling.

The mentioned climatological conditions, which affect the choice of an active mode of transport, deteriorate with the projected climate scenario's and thus affecting the health of people in a negative way; climate change worsens the already existing problem of less people picking the bike in case of uncomfortable weather conditions and therefore a solution is needed to tackle the upcoming problem.

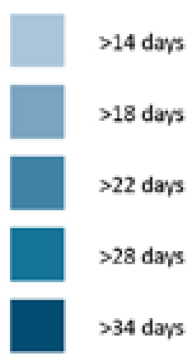


Figure 1.2: Urban Heat Island effect Rotterdam 2050 W+ scenario.

1.4 Research area

	<5 km	5 to 14 km
Rotterdam	23%	16%
Amsterdam	38%	30%
Den Haag	28%	19%
Utrecht	40%	30%

Figure 1.3: Amount of bicyclists in the four big municipalities (Rotterdam, 2015)

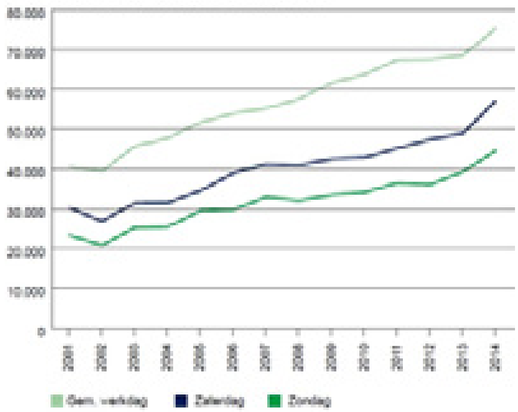


Figure 1.4: Growth of bicyclists in Rotterdam (Rotterdam, 2015)

The **Netherlands** offers a very good opportunity to start with a healthier lifestyle by using more active modes of transportation. 28% of all Dutch people use the bike regularly as mentioned in chapter 1.2. When the four big Dutch cities (Rotterdam, Amsterdam, Den Haag and Utrecht) are compared in cycle-use in case of distances below 5km and from 5km till 14km, **Rotterdam** scores the lowest for both distances (figure 1.3). Fortunately, Rotterdam is already trying to improve their bicycle share. The municipality aims for an increase of 10% more cyclists in the period of 2015-2018 (figure 1.4). They are investing 2.17 million Euros to improve the bicycleing infrastructure (Rotterdam, 2015).

The municipality assigned multiple problem streets (red) and spots (orange). One of them is the main bicycle route, city-axis Schiekade – Wilhelminaplein. The other problem routes are Boezemweg, Goudse Rijweg and a part of the Bergweg (figure 1.5). Schiedamsedijk – Posthumalaan is the most southern route of all problem routes. The route crosses the Erasmusbridge and is one of the busiest routes with 10.968 cyclists on workdays, 8.593 cyclists on Saturdays and 7.409 cyclists on Sundays (Rotterdam, 2015).

Figure 1.5: Problem routes are highlighted in red (Rotterdam, 2015).

The route is south and southeast oriented. Goudse Rijweg is west – east oriented. The street is quite small and the buildings are quite high compared to the street (3-4 floors). Boezemweg crosses Goudse Rijweg and is south – north oriented. The Bergweg is the problem street at the north side of the Coolsingel. The street is southwest – northeast oriented. The problem routes are the busiest routes of the city Rotterdam and are problematic in case of; waiting times for red lights, there is not enough space to wait by crossings and outdated infrastructure (Rotterdam, 2015). The fact that the most people of Rotterdam cycle along these routes, means that most of the people experience the (bad) weather at these routes. Therefore are these problem routes used as research case, to achieve a maximum impact.

A lot of research is already done in Rotterdam towards the cycle use in combination with climate/weather. This forms an additional reason to use Rotterdam as reliable research area. The results of this thesis are scalable and can also be used in (harbour-)cities with a temperate (Maritime) climate, which is characterized by mild winters (average lows of 1 °C and highs of 6 °C), warm summers (average lows of 12 °C and highs of 21 °C), and relative stable seasonal precipitation patterns (KNMI, 2016).

Figure 1.6: Problem routes and street names

1.6 Conceptual framework & knowledge gap

The problem can be separated in different parts which could lead to an answer for the stated problem; ''Climate change (1) worsens the already existing problem of less people using the bike in case of uncomfortable weather conditions (2, 3).''

First, information about the effects of climate change is commonly described in different sources (IPCC, 2007; KNMI, 2015). The climate scenarios are based on existing knowledge since 1900, and predict what could happen in the future for climate and weather. Thereby does the information about climate change not provide accurate answers which implications this has for the city (Rotterdam in this case) or urban environments.
Second, why less people picking the bicycle or using active modes of transport during certain types of weather is described in a collection of literature (Böcker, 2014; Böcker & Thorsson, 2014; Helbich, Böcker, & Dijst, 2014). These researchers also tried to connect environmental valuations during certain weather phenomena, but did not succeed to link greenery or building density to their valuations during their trips.
Third, more researcher know why certain weather phenomena cause uncomfortable perceptions of people (Brown & Gillespie, 1995; Klemm, Heusinkveld, Lenzholzer, & van Hove, 2015; Lenzholzer, 2012, 2013). But did not apply this information specifically to moving persons or more specific, cycling people. However this information is not specific about cycling people, it provides good insights how to deal with thermal perception for stationary people.

For the separate parts literature can be found, but for a combination of these subjects in literature does not exist yet. Keeping in mind this research is set in a landscape architectural setting, information how to design for the above mentioned problem is required. As described in the third point, the information is mainly focused on stationary people. Derived from the above described framing is noticeable that more knowledge is needed how to deal with designing solutions, in order to improve the thermal perception of cyclists during uncomfortable weather conditions.

2. Research design

2.1 Landscape architectural perspective

This thesis is written and designed from the mind of a landscape architect. Landscape architecture is the architecture of the differentiated, enclosed outdoor space. It is a fusion of art, nature and functionality in a designed composition. The landscape architect shapes this fusion (Vroom, 2010). Drawing, mapping, visualising, representing, and giving shape, are the unique activities that constitute the act of designing (Lenzholzer, Duchhart, & Koh, 2013). Even though this definition is still there, change is happening in the way how the discipline occurs;

''After more than a century of growth, the discipline of landscape architecture is now taught in a number of countries, universities and languages, and addresses a wide range of public and private needs at a variety of scales. As the discipline continues to expand and engage with other disciplines to address the profound human and environmental challenges of the 21st century, there is growing need and demand to deepen the way we think, and to be able to better justify our intentions as designers and planners, and our actions as agents of environmental change'' (Deming & Swaffield, 2011, p.34).

This thesis is conducted in a pragmatic perspective, because landscape architecture arises out of the need for actions, situations and consequences. The landscape architect bases his/her decisions on a broad scale of knowledge and is not specifically bound to one system of philosophy (Creswell, 2014; Deming & Swaffield, 2011; Vroom, 2010).

2.2 Research questions

Since this thesis was conducted in a landscape architectural perspective, the outcome will be design focused. This leads to a research question which is both design- as researchoriented. The main research question (MRQ) which provides an answer to the stated problem is;
Which solutions can improve the thermal perception of cyclists during uncomfortable weather situations?

The problem statement shows that wind, cold, precipitation and too hot weather conditions (above 24 °C) are seen as uncomfortable weather conditions to participate in an active mode of transport (Böcker, 2014; Böcker & Thorsson, 2014; Helbich et al., 2014).
When thinking of a possible design, multiple weather probles could be solved with design solutions on the urban scale. But cold and hot weather conditions could not be alternated in order to change the air temperature or relative humidity. It is possible to design with wind, precipitation and short wave radiation or solar radiation in order to influence thermal perception of a person (Brown & Gillespie, 1995; Lenzholzer, 2013).
The research needs to be divided in smaller pieces in order to answer the main question. This thesis is divided in 2 large parts; The Research <u>For</u> Design part and the Research <u>Through</u> Design part.

Research for Design
Research for design (RFD) is described as; *''This category covers all types of research that support the design product or design process. Here, both product and process benefit from research activities in the sense that the research outcomes inform the design process''* (Lenzholzer, Duchhart, & Brink, 2016, p. 2).

This Research for Design part answers the questions;
(SQ1) What does influence the thermal perception of a cyclist?
(SQ2) Where along the problem routes, do certain influences cause bad thermal perception for cyclists?
(SQ3) Which spatial configurations could be identified as problematic on the found uncomfortable routes?
(SQ4) Which conditions must be considered while designing solutions for the problematic spatial configurations?

Research through Design
The second part uses Research Through Design in order to synthesise solutions for the stated problem. Research Through Design(ing) is described as; *''covering all the research processes that actively employ designing. Research through designing (RTD) is at the heart of all design disciplines''* (Lenzholzer et al., 2016, p. 3). RTD is the research process that covers the act of designing, requires the involvement of design experts and is often conducted in cooperation with other disciplines (Lenzholzer & Brown, 2016; Lenzholzer, Duchhart, & Koh, 2013).
Since this thesis is written in a pragmatic worldview, the definition can be described in a more specific way; *''Research questions posed within pragmatic RTD concern natural and cultural aspects as well as design procedures, often within a certain geographical context''* (Lenzholzer et al., 2013, p. 125). Therefore is the RTD part separated in 2 parts; RTD part 1 and RTD part 2. Where the first part generates solutions for the separated weather problems (natural aspects); wind, shortwave radiation and precipitation by answering the following questions;

(SQ5) What are possible design solutions to improve thermal perception of a cyclist coping with wind?
(SQ6) What are possible design solutions to improve thermal perception of a cyclist coping with short-wave radiation?
(SQ7) What are possible design solutions to improve thermal perception of a cyclist coping with precipitation?

The second RTD part integrates the separated solutions and also implements them in the research area Rotterdam, which involves cultural aspects. The last part provides answers to the main research question; which solutions can improve the thermal perception of cyclists during uncomfortable weather situations?

2.3 Methodology

The RFD part sets the preconditions of designing solutions. SQ1 creates a framework for understanding what is important for designing with thermal perception of a cyclist. The questions SQ2 and SQ3 detail the actual problem, which results in detailed, generalized test beds. All-important preconditions out of SQ1 till SQ3 are used to form the 'criteria' of SQ4. These criteria are used to test the solutions of the 'research through design' parts.
The RFD is performed as a mixed methods research, which involves the collection of both qualitative and quantitative data and includes an analysis of both forms of data. The two forms are later merged in the thesis by connecting the data in later phases of this research (the RTD parts). The mixed methods can be seen as a quite new methodology originating around the late 1980s and earlier 1990s based on work from individuals in diverse fields such as education, management, sociology and health sciences. This thesis makes use of the mixed methods, because this method incorporates both the strengths of quantitative and qualitative research and therefore provides a more complete understanding of the stated problem (Creswell, 2014). This subchapter describes the used methods and tools in order to solve the sub-questions mentioned in chapter 2.2.

(SQ1) What does influence the thermal perception of a cyclist?
Literature is used to frame the problem and specify the quantitative and qualitative sides of this thesis. This chapter frames what is important for the cyclists and which problems should be solved in order to accomplish a better thermal perception for cyclists.

(SQ2) Where along the problem routes, do certain influences cause bad thermal perception for cyclists?

This chapter is separated in a quantitative (physical influences) and a qualitative part (psychological influences). First the quantitative part is discussed and analysed, which contents a shading- and a wind analysis.

A shading model is built as part of the microclimate analysis. Google Sketchup is used to find the less exposed spots and the more exposed spots of the assigned problem streets. AHN or Algemeen Hoogtebestand Nederland (Common Altitude file Netherlands) is used to find the correct height data of building heights, tree heights and street levels (AHN, 2016). Bing Maps is used as a reference to rebuild the buildings along the routes. This Sketchup 3D model (figure 3.1) is used to form multiple shots during the day in time-steps of 2 hours. In the winter the shots are made at 10:00, 12:00, 14:00 and 16:00 on the 21st of December 2016. In the summer the shots are made at 08:00, 10:00, 12:00, 14:00, 16:00, 18:00 and 20:00 on the 21st of June 2016. Summertime and wintertime are used and by using the same coordinates as the buildings (which are retrieved from GBKN via AutoCAD), lengths and angles of the shading are calculated by Google Sketchup. These shading shots are manually analysed with the use of Adobe Illustrator CC 2015.

Educated guesses are used to analyse the wind patterns and flows in the study area. The expression 'educated guesses' designate a guess that, far from being wild, is compatible with some background knowledge (Bunge, 2012). The educated guesses on wind flows and patterns are based on acquired knowledge about wind patterns and wind flow behaviour, which could be found in multiple books (Brown & Gillespie, 1995; Landberg, 2016; Lenzholzer, 2013). Programs such as Autodesk Flowdesign provide practical insights how wind flows from certain speeds and angles.

The qualitative part is conducted in another way as the quantitative part. Lenzholzer mentions 3 types of methods to map the psychological/qualitative influences of the environment; mental maps, interviews and observations (Lenzholzer, 2013).

Mental maps are built from information gained from interviews with users of the outdoor space. This information can provide detailed information about where people evaluate the outdoor space as less pleasant or thermally uncomfortable. A drawback to this method may be that not all spots of the route are covered in the information supply (Lenzholzer, 2013). Good conclusions cannot be drawn with inconsistent information.

Interviews are useful when information about the general thermal perception of the environment is required. Böcker uses this method to gain knowledge and understand the way cyclists perceive the environment during uncomfortable weather conditions. En-route place valuations (in terms of liveliness, friendliness and aesthetics) are mostly affected by dynamic rather than static spatial attributes (greenness, building usage diversity and address density). People value their travel surroundings more positively when traveling accompanied by others, for leisure, during daytime, or with a detour (Böcker, 2014). Unfortunately is this outcome not space related and detailed information per street is missing.

The third method is observations, which is a useful method when small microclimatic interventions are desired. The aim is to map the behaviour of the people during different times and seasons. This method requires multiple research moments and quite a variety of movement (Lenzholzer, 2013). Cyclists are dependent on the existing cycle paths, and it is not desired to cycle elsewhere. Therefore is this method not very useful.

Another method is required to map the atmosphere. In order to research this qualitative subject, a qualitative visual analysis is possible. This data may take the form of photographs, art objects, videotapes, website main pages, etc. The visuals provide visual narratives about the researched object (Creswell, 2014). Collages of sphere-setting elements of the streets and a colour palette to show the warmth/cold of the used colours in the streets are used to analyse the qualitative part of this thesis. Photos from eye-height are used for this analysis, because this is the perspective for cyclists. These photos are taken by the author during a site visit.

(SQ3) Which spatial configurations could be identified as problematic on the found uncomfortable routes?
This question combines the previous parts and interpreters them. The conclusions of the quantitative and the qualitative parts are visualised in maps and layered in order to find overlapping results. These overlapping results are the most problematic areas or configurations of the analysed routes. Combining the results in this way is typically for 'convergent parallel mixed methods' (Creswell, 2014). The results are than generalised (in measurements per spatial configuration) in order to come with test beds to design solutions upon.

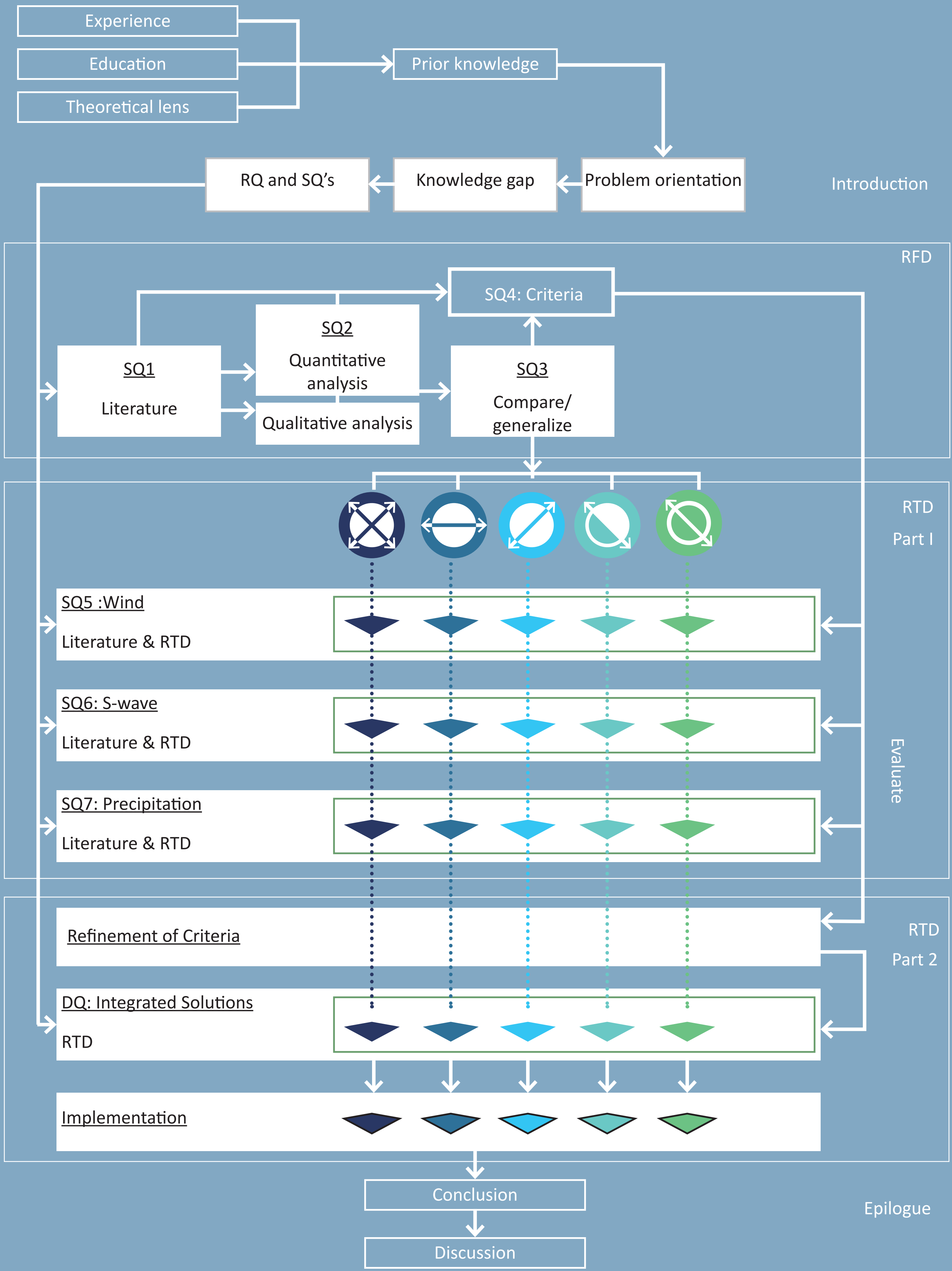
(SQ4) Which conditions must be considered while designing solutions for the problematic spatial configurations?
The designed solutions in the RTD parts should be based on the important aspects of the RFD part of this thesis. All important aspects of the RFD part are taken into consideration to set the preconditions for new design solutions. These preconditions are the elements which are already there or should be improved with the new designs.
In order to set an equal base of evaluation, an assessment matrix is used. The upcoming design solutions are evaluated in a qualitative way according to a rating scale. The solutions will be assessed with plus/minus rating, varying from; ++, +, 0, - and --. The more positive a criterion is assessed, the higher the design solution scores. The most optimal or satisfying solutions will have the highest scores.

(SQ5,6 & 7) What are possible design solutions to improve thermal perception of a cyclist coping with wind/shortwave radiation/precipitation?
In contrast to natural scientists, designers often deal with problems which are not well formulated, ill-structured or open ended, also described as 'wicked problems' (Rittel & Webber, 1973). In a complex design process these ill-defined problems can occur and require continues compromising, and the outcomes of the testing and refining cycles cannot be 'optimal', but rather 'satisficing' (Simon, 1996). Larger degrees of complexity and scale therefore need to be addressed through several iterations in the design process. Essentially, the design products and hypotheses are tested and optimized in an iterative process.

In case of the problem routes of Rotterdam, there are also ill-defined problems. These problems are not only based on infrastructural problems, but interfere with macro-, meso- and microclimate problems. A method is needed to find the most satisfying solutions dealing with thermal comfort of cyclists. The RTD method is used, because it uses the act of designing to generate new knowledge based on existing knowledge. This designing is needed in order to fill the stated knowledge gap. The existing knowledge is based on empirical research (RFD part of this thesis) and is translated in design solutions by designing (RTD part 1 and 2 of this thesis).
The above mentioned questions are answered by designing solutions per problem; wind, shortwave radiation and precipitation. These solutions are designed in the generalized test beds of SQ3. All the designed solutions are tested and evaluated according to the assessment matrix of SQ4.

(MRQ) Which solutions can improve the thermal perception of cyclists during uncomfortable weather situations?
The separate solutions per problem (wind, shortwave radiation and precipitation) are combined in the second iteration phase; integration. These solutions are tested and evaluated according to a refined assessment matrix. This refinement is needed and natural in the design process, and subject to the learning process (Cross, 2006; Rittel & Webber, 1973). This learning process is stimulated by expert meetings, where the solutions are discussed. These expert meetings consist of teachers/microclimate experts and MSc students of Landscape Architecture, focussing on microclimate topics. One highest scoring solution per test bed is the end result of the integrated iteration phase.
These highest scoring solutions are detailed and implemented in real life situations. This means that the generalized solutions are tailored for certain places in Rotterdam. These solutions are further detailed (colours, shapes, materials) according to the outcomes of the qualitative research part (RFD). This third iteration of designing is called the 'implementation' phase and provides the most 'satisficing or optimal' answer on the MRQ.

Figure 2.1: Methods scheme



Experience
Education
Theoretical lens
Prior knowledge
Problem orientation
Knowledge gap
RQ and SQ's
Introduction
RFD
SQ4: Criteria
SQ2
Quantitative analysis
Qualitative analysis
SQ1
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RTD
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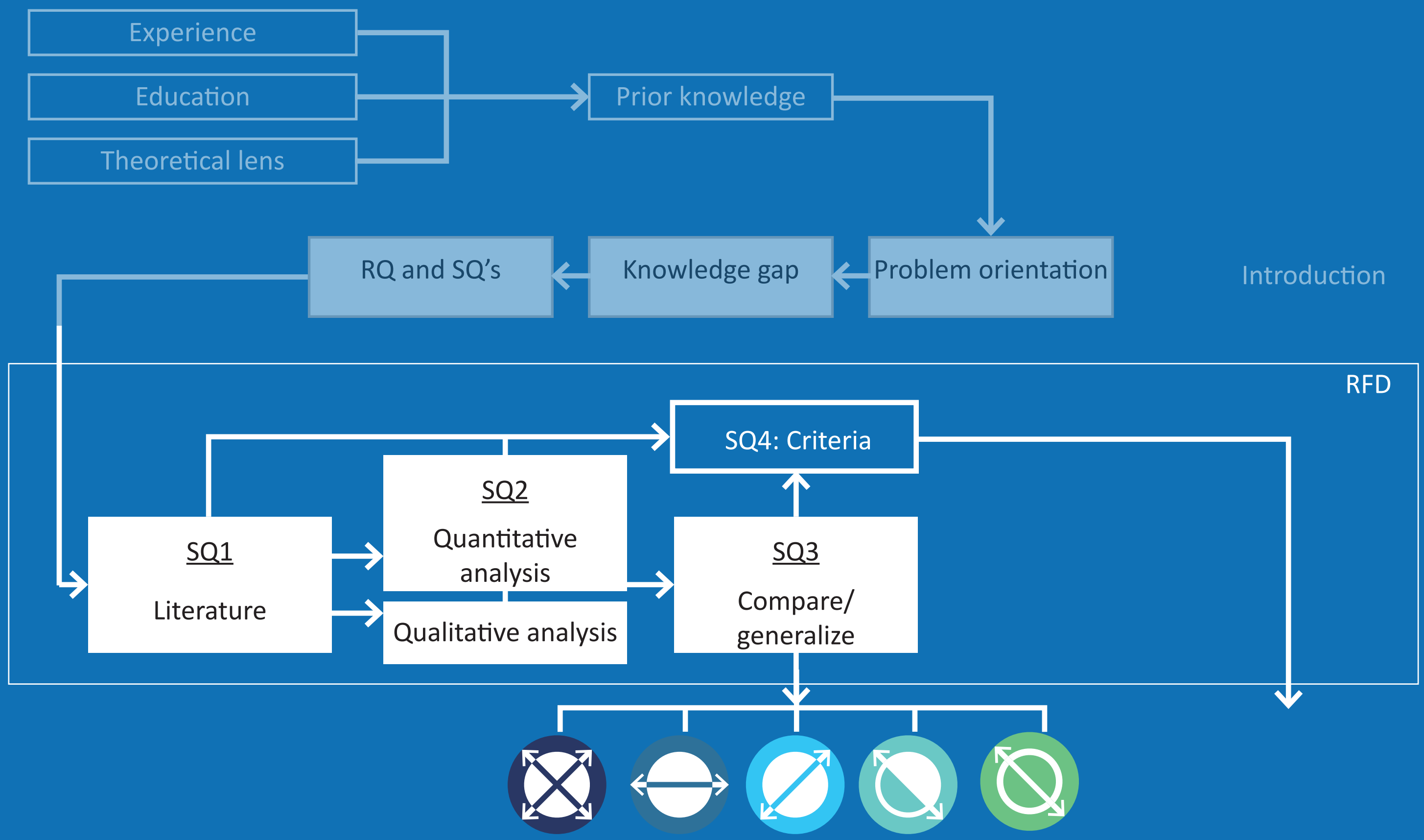
Research For Design

This part focusses on finding the components influencing the thermal perception of a cyclist (SQ1). Second, this parts searches for the places along the problem routes where certain influences cause bad thermal perceptions for cyclist (SQ2). The problematic spaces are combined and generalized in order to define spatial problematic configurations (SQ3). And finally the preconditions are described (SQ4) which will be used to evaluate the solutions of RTD part 1.


Experience
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Knowledge gap
Problem orientation
Introduction
RFD
SQ4: Criteria
SQ2
Quantitative analysis
SQ1
Literature
Qualitative analysis
SQ3
Compare/ generalize

3. Theoretical framework

3.1 General thermal perception

This chapter aims to find an answer to the first sub question; What does influence the thermal perception of a cyclist? Thermal perception is influenced by many factors. These factors can be separated as: Internal/individual physical and physiological factors, external physical factors and psychological factors (Brown & Gillespie, 1995; Lenzholzer, 2013). These factors are explained in the following subchapters. First, the general thermal perception influences are discussed (3.1). Second, the thermal perception influences of cyclists are discussed in 3.2.

3.1.1 Internal physical and physiological factors

Internal physical and physiological factors are age, sex, thermal history, metabolism, activity, climate acclimatization and clothing. Men are less sensitive for perceiving temperature differences than women, older people are more sensitive to cold or warmth than younger people. Thermal history can be explained as when someone walks from a warm room to another environment which is much cooler; the person does not cool down immediately, because the person is warmed up in a warmer environment. The rate of metabolism or activity also heats up the human body if the rate is higher than the rest situation and therefore contributes to the thermal perception. People from warmer countries are used to warmer climates, thus feel cold faster than the average Dutch person in the Netherlands. This is called climate acclimatization. The amount of clothing regulates the amount of warmth which is hold by a person (Brown & Gillespie, 1995; Lenzholzer, 2013).

3.1.2 External physical factors

External physical factors are wind speed, longwave radiation, shortwave radiation, air temperature and relative humidity. The perception of air temperature could be sensed easily. However to change this component is dependent of large scale design interventions to form a major impact on air temperature. Longwave and shortwave radiation are factors which heat up the body directly or indirectly via sunshine. Shortwave radiation originates from the sun, or a reflection of direct sunlight. This shortwave radiation is partly stored in materials such as stone during the day. This radiation is emitted during the night (and partly during the day) in the form of longwave radiation. A higher wind speeds creates more convection on the human body by its air-resistance and the human body cools down because of this convection. Relative humidity influences the temperature experience, because it could block the release of sweat during high humidity conditions. The thermal perception is valued negative in this case (Brown & Gillespie, 1995; Lenzholzer, 2013).

3.1.3 Psychological factors

Psychological factors are mood, company, environment and atmosphere. If an individual is together with others, he or she feels more positive about the environment than someone who rides alone (Lenzholzer, 2013). Mood is influenced by many factors such as weather conditions. Low sky clearness indices representing cloudy weather result in less pleasant emotional travel experiences, while sunny weather situations enhancing serotonin in the brain (Lambert, Reid, Kaye, Jennings, & Esler, 2002), which leads to more pleasant emotions. Atmosphere is also influencing the thermal perception of people. If a room is comfortably furnished, people judge their thermal perception as warmer than when the room is not furnished, even though the room temperature was the same in both rooms (Rohles, 1981).

3.1.4 Editable by design

Multiple factors influence the thermal perception of an (stationary) individual. However not all factors could be influenced by designing and also not on every scale of designing. Air temperature and relative humidity can only be tackled on urban or even regional scale (Lenzholzer, 2013). Wind speed, shortwave radiation, longwave radiation, environment and atmosphere can be influenced on the smaller scale such as street scale or urban scale (Lenzholzer, 2013).

3.2 Thermal perception of a cyclist

Thermal perception of a cyclist is different from the general thermal perception. The differences are described according to the same factors of the 'general' thermal perception of 3.1.

3.2.1 Internal physical and physiological influences

Thermal perception factors which are affected by bicycling are; thermal history, metabolism and activity. If someone is exposed for a longer time to uncomfortable weather conditions, he or she might value the end of the journey lower than the beginning of her/his journey. The thermal history affects thermal comfort in a linear way. The longer the journey, the lower the thermal comfort levels are in case of uncomfortable weather conditions (Böcker, 2014). Metabolic rate or energy depends on the activity. A body in rest generates about 90 watts of energy per square meter, but a cycling person can generate between 120 W/m2 and 400 W/m2 depending on the resistance (wind or elevation/slope) and how fast the person cycles. This metabolic rate warms up the body and thus influences the thermal perception of the person (Brown & Gillespie, 1995). Influences such as age, sex, climate acclimatization and clothing are components which could not be altered by designing.

3.2.2 External physical influences

Temperature is one of the guiding conditions for using the bike or not. Temperature seems to have a non-linear effect on transport mode choice. The optimum is between 15 °C and 24 °C, high temperatures (higher than 24 °C) and low temperatures (below 15 °C) have been found to negatively affect cycling in the Netherlands. Studies show a more or less linear negative effect on walking and cycling when it comes down to precipitation sum and wind speed. The weather has a positive linear effect on car use with the increase of temperature (above 24 °C), precipitation sum and wind speed (Böcker & Thorsson, 2014). The exposure to wind or precipitation, or a combination of both as wind driven rain, may have direct implications for comfort levels. For instance related to raindrops in the eyes, flapping clothes, hair disturbances or even losing balance and being blown over (Blocken & Carmeliet, 2004). People on bikes are even more vulnerable for the above mentioned implications and could value the environment less attractive during uncomfortable weather conditions. Static spatial attributes such as greenness, building usage diversity and address density are less effecting en-route (on the way) place valuations, than dynamic spatial attributes such as weather conditions (Böcker, 2014). Short wave radiation is also affecting cyclists but is not very different from impact from a walking person. Relative humidity is affecting the cycling experience because the metabolic rate is higher than a walking, which means the person is losing warmth by sweating. If the relative humidity is higher, the thermal perception is lower, because the individual has more difficulties to loose sweat by evaporation. Another factor which is important when designing for cyclists, is coping with convection. This is the process of wind carrying heat from a person's body away. The amount of heat carried away depends on the temperature difference between the person and the air, and on the speed at which the air is moving. If the wind speed is higher, the cooling effect on skin temperature is also higher. In other words, the faster a cyclist rides, the more air molecules deprive from the cyclist's body. During cold weather conditions this cooling effect could lead to thermal discomfort (Brown & Gillespie, 1995).

3.2.3 Conclusions

An overview of the previous results will be given in order to answer the first subquestion; (SQ1) What does influence the thermal perception of a cyclist?

Internal physical and physiological factors: As a landscape architect it is possible to decrease or heighten metabolic rate (altering slope or resistance of wind pressure). Tailwinds can help to decrease metabolic rate, thus warmth from within the cyclists. This thesis does not alter slopes of streets, because the main situation should stay intact (and altering slopes causes unrealistic costs).

External physical factors: Cyclists should be protected from wind during cold days, but wind is allowed during warmer days. Cyclists should be shaded for temperatures higher than 24 °C, no shading is needed when temperatures are below 15 °C. Cyclists should be protected from precipitation during colder situations. below is shown the internal and external physical influences on a cyclist during a cold day (figure 2.1) and during a warm day (figure 2.2).

Psychological factors: The cyclists should receive as much shortwave radiation as possible, which means a good light intrusion is preferred to enhance pleasant emotional travel experiences. Factors such as company are also possible to facilitate as a landscape architect by designing wide paths. Cyclists can be manipulated in their thermal perception by altering atmosphere.

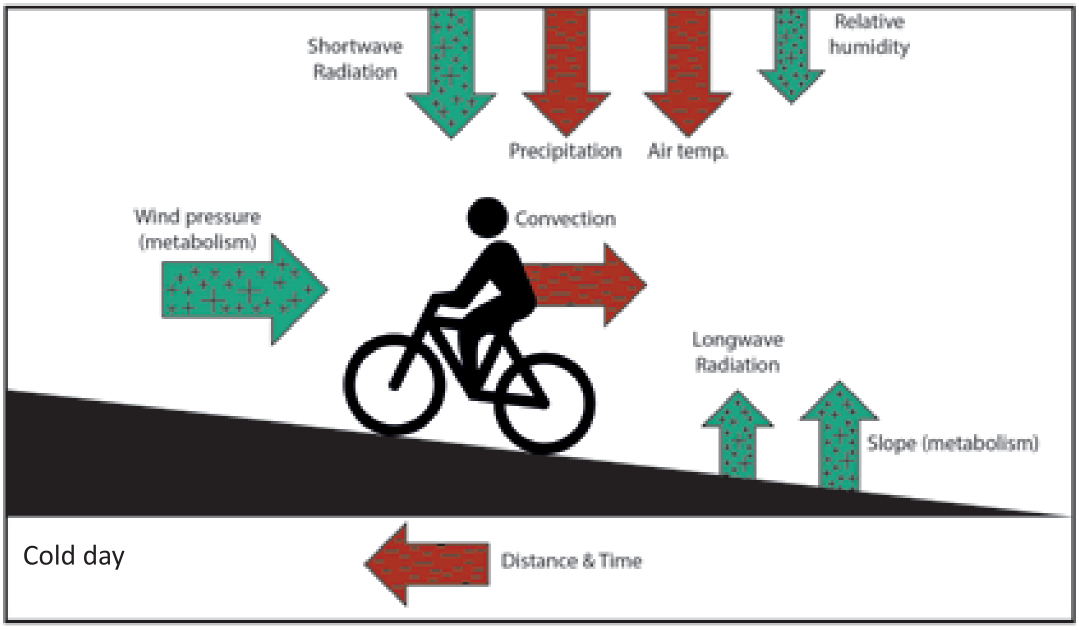
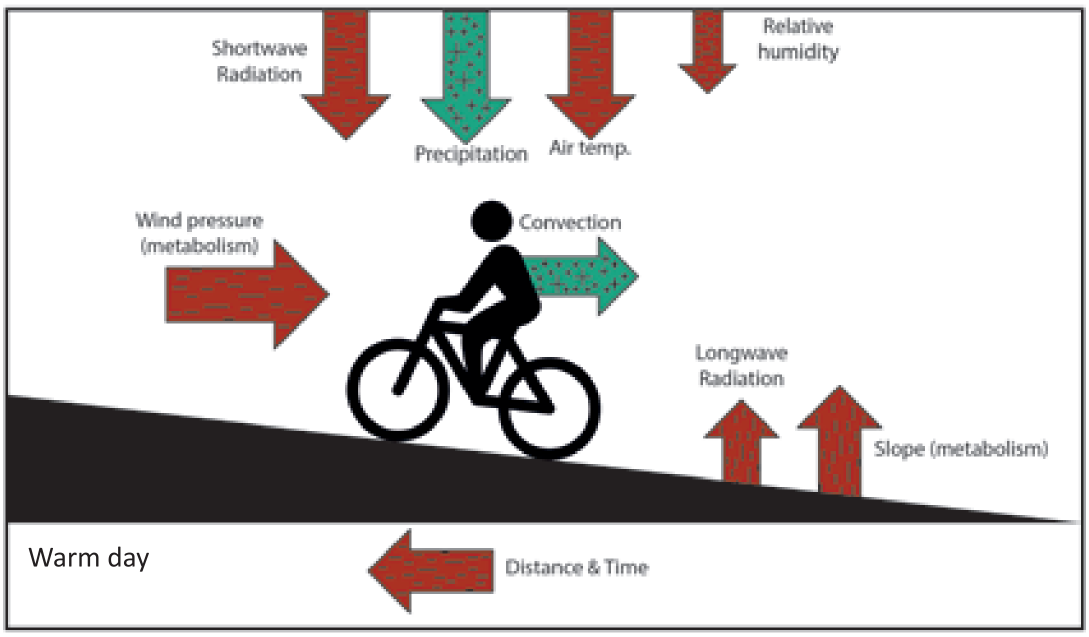


Figure 3.1: Climate influences on thermal perception of cyclist during a cold day



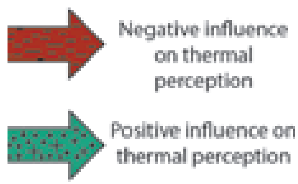


Figure 3.2: Climate influences on thermal perception of cyclist during a warm day

4. Site analysis

The following question is answered in this chapter;
(SQ2) Where along the problem routes, do certain influences cause bad thermal perception for cyclists?
As mentioned in chapter 3, external physical influences and psychological influences are the components of thermal perception which can be altered by designing. The problem routes of Rotterdam are analysed to find the areas/spots which are the worst in terms of thermal perception for cyclists.

4.1 External physical influences

Weather can have different effects on cyclists, relying on different spatial configurations where this cyclist is moving through. This subchapter describes where the weather has the largest effects on the external physical influences of thermal perception of a cyclist. The chapter is divided in 2 sub-chapters; shortwave influence and wind influence. Precipitation influence is not analysed because the effect of precipitation on cyclists is equal along the assigned problem routes (Helbich, Böcker, & Dijst, 2014)

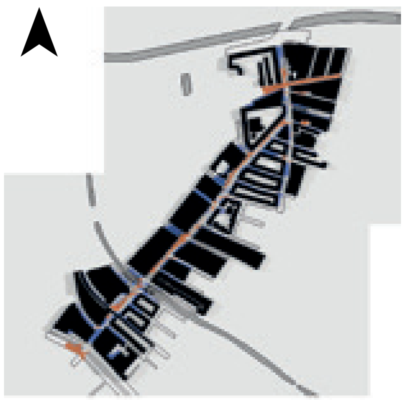
4.3.1 Temperature influence

Air temperature has an overall positive bell-shaped effect on cycling. Higher air temperatures increase the likelihood for cycling until a certain optimum (24 C°), after which the cycling probability decreases (Ahmed, Rose, & Jacob, 2010; Lewin, 2011).

A 3D model is built in Google Sketchup (figure 4.1), in order to find the more exposed spots and less exposed spots for shortwave radiation. This 3D model is built and analysed according to the methods of chapter 2.3 (SQ2). The images are manually analysed in Adobe Illustrator CC 2015. The 2 darkest shades are less exposed spots (blue) and the 2 lightest shades are more exposed spots (red) in the summer images. The darkest shades are less exposed spots (blue) and the lightest shades are more exposed spots (red) in winter images. The result of the analysis is shown in figures 4.2, 4.3, 4.4 and 4.5.

More exposed spots could form problematic areas in summer and can heat up the environment to 10 C° via stored heat in the form of longwave radiation (Böcker, 2014). Thermal perception is highly influenced by shortwave radiation; the direct impact of the sun could heat up the body with several degrees which causes the body to sweat to loose heat. During warm days too much of this short wave radiation could cause uncomfortable thermal perceptions of people or even heat stress is possible (Lenzholzer, 2013).

Figure 4.1: 3D Sketchup model of assigned problem routes Rotterdam

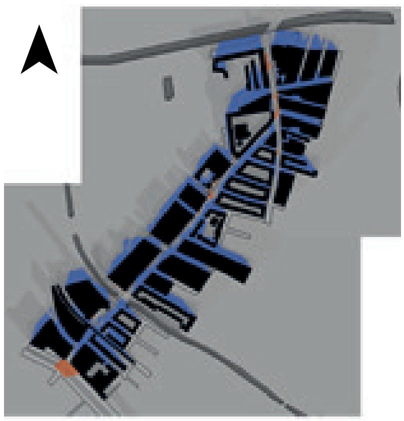


More exposed spots (shortwave)

Less exposed spots (shortwave)

Figure 4.2: (left) Shading and shortwave analysis summer

Figure 4.3: (right) Shading and shortwave analysis summer of Bergweg



More exposed spots (shortwave)

Less exposed spots (shortwave)

Figure 4.4: (left) Shading and shortwave analysis winter

Figure 4.5: (right) Shading and shortwave analysis winter Bergweg

Therefore it is necessary to know where these more exposed spots are located, to tackle this problem and to improve the thermal perception of cyclists. Similarities could be found in analysing the more exposed spots. The more a street is west to east oriented, the longer the street is radiated by the sun, especially in summer where the sun is very high and creates short shadows. These situations are found at the Coolsingel, Schiedamsedijk and Boezemweg, but also the whole Goudse Rijweg is problematic in case of short wave radiation during warmer days. Posthumalaan is northwest – southeast oriented and does not have many trees and buildings to provide shade and therefore is also problematic during warmer days. Bergweg is southwest – northeast oriented and is less problematic than Goudse Rijweg, because part of the day the street is shaded by buildings and trees.

In winter situation trees are eliminated in the Sketchup model, because all trees in the project area are deciduous trees, which means they don't or almost don't provide shade during winter because the loss of leaves. The more the street is West to East oriented, the more problematic. The sun angle is lower in winter and thus longer shades occur along the day. Problematic streets during the winter are Goudse Rijweg and Bergweg. These streets are in the shade for almost the whole day. A few crossings along Posthumalaan, Schiedamsedijk, Coolsingel and Boezemweg are problematic because they are surrounded by tall buildings, which provides shade for most of the day. In the figures below is shown where the problem areas are located for the summer (figure 4.6) situation and the winter (figure 4.7) situation.

Figure 4.6: (left) More exposed spots in summer.

Figure 4.7: (right) Less exposed spots in winter.

4.3.2 Wind influence

The areas near the water are more exposed to wind compared to the more built areas. The wind in the city centre of Rotterdam deviates, but the dominant wind direction is from the southwest direction (KNMI, 2016). The city centre as well the adjacent area in the North East named Rotterdam Alexander, demonstrate a relative strong negative effect of wind on cycling (figure 4.8). This may seem remarkable, as a densely built city centre provides much shelter with its many objects. However, the city centre of Rotterdam and Rotterdam Alexander consists of many free-standing high-rise buildings, which is combined with some open spaces, such as major rivers, and a dominant wind from the sea, may create a highly turbulent and potentially uncomfortable gusty environment for cycling (Helbich et al., 2014). The central area in Rotterdam is affected by the wind through the larger buildings which are located in the city centre. These larger buildings create turbulence in the northeast side of the larger buildings, because the wind generally blows from southwest directions (KNMI, 2016). These winds could also create downdrafts on the façades of the buildings (Lenzholzer, 2013), and gusty cycling environments are occurring during days with higher wind speeds.

Figure 4.8: Wind influence on cyclists, Rotterdam. Edited from Helbich et al., 2014

Wind blows from the southwest direction in Rotterdam (KNMI, 2016). This data is used to render a wind problem map, which is illustrated in figure 4.9. Blue indicates areas where wind has free space to accelerate and therefore are high pressure/velocity areas. Orange shows the lee areas, thus the areas where wind does not accelerate and where negative pressure areas are prominent. Corners and façades create friction, which leads into corner streams, drafts and downwash of wind. These winds are relative high speed winds and form turbulence around corners, wind facing façades and behind buildings (Brown & Gillespie, 1995; Lenzholzer, 2013). These drafts are illustrated as a swirl in figure 4.9. The more a street is southwest oriented, the larger the problematic and cooling winds are. If a street is wider and/or longer, the more wind is free to blow through this street, and is able to accelerate (Landberg, 2016). If buildings, trees and other objects in the street do not provide protection against wind (for example Erasmusbridge and Posthumalaan), the more wind is able to accelerate. These winds are more able to accelerate to their maximum potential. These fast winds could conduct pressure on cyclists and form more resistance for these cyclists. Cyclists are moving faster through the environment than for example a walking person. This faster movement surprises cyclists of sudden high speed winds or turbulence, where a walking person is more able to anticipate on these winds.

Figure 4.9: Wind analysis for southwest winds

Large differences in pressure (e.g. from a lee side into a corner stream) create dangerous situations and less thermal comfort during colder days (Blocken & Carmeliet, 2004; Lenzholzer, 2013). The problematic streets and dangerous spots are marked (orange) in figure 4.10.

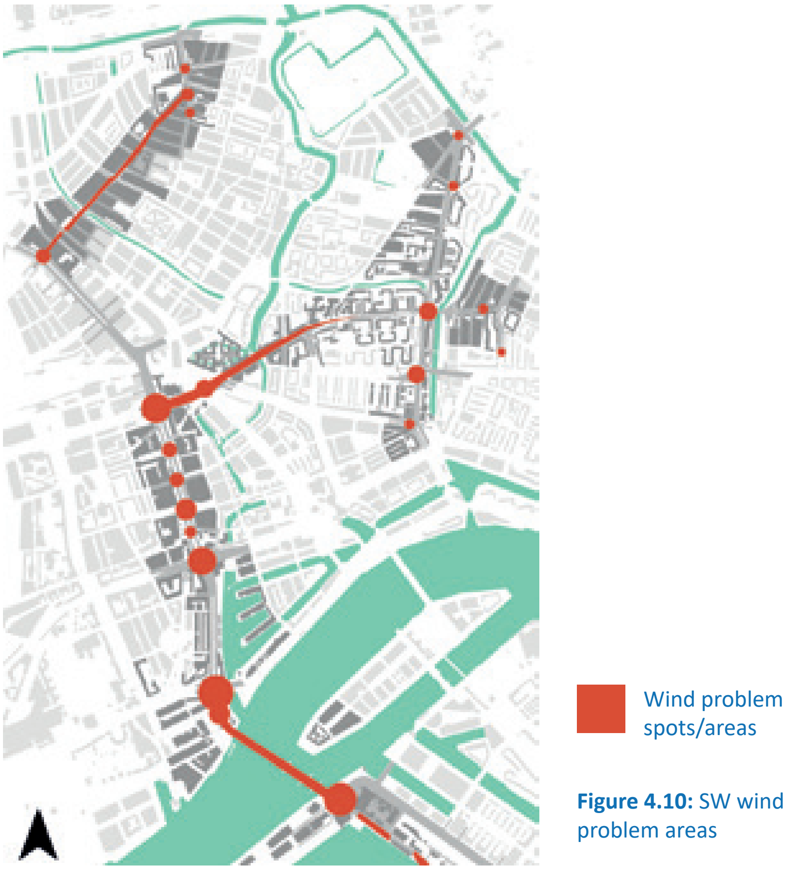


Figure 4.10: SW wind problem areas

4.2 Psychological influences

This subchapter describes the qualitative analysis part, which is mainly focused on the psychological influences of the thermal perception of cyclists. Although psychological influences do not alter air temperature or radiation, it influences the thermal perception of cyclists in a psychological way. As mentioned in the methods chapter 2.3, multiple methods are used to analyze this qualitative element. The history of the buildings and built environment is used in order to set an atmosphere of style, which is characterized by certain style-elements. Photos are taken and analyzed by a color palette and by the use of Jan Gehl's book. Gehl categorizes several types of streets and outdoor environment from less attractive to more attractive environments (Gehl, 2010, p. 240-241). This chapter concludes with an overview of problematic streets in case of atmosphere.

4.2.1 Posthumalaan and Erasmusbridge

This part of the route is still work in process, which started during the 90's (Spaan & Waag-Society, 2015). Kop van Zuid and Wilhelmina pier are almost finished and consist of large and tall buildings. The Erasmusbridge is opened in 1996 and designed by Ben van Berkel (Boom, 2017). These streets and bridge consists of large structure buildings with fewer doors to the street (0-2 doors per 100m) and almost no variation in function (primarily work/companies). Many façades are blind or are not very interesting in terms of detailing of the buildings. Water seems to be the most aesthetic feature to look at. The buildings are architectural impressive but the outdoor space is characterless (Gehl, 2010), which makes this part of the route more a move through space for cyclists.

The bridge and buildings are made of steel, stone and concrete. Large glass façades and smooth cladding is dominant on most of the buildings. Post-modernism is the main architectural style used for all the buildings along this route (Boom, 2017).

A larger amount of colder colours occur on this part of the route. Although the cool colours are dominant, warmer colours are used for certain buildings along the route. These colours are contrasting with the water and cool colours of other surrounding buildings. This variation provides more liveliness in terms of 'what to see', but is still not inviting enough to stay for a longer period of time (Gehl, 2010).

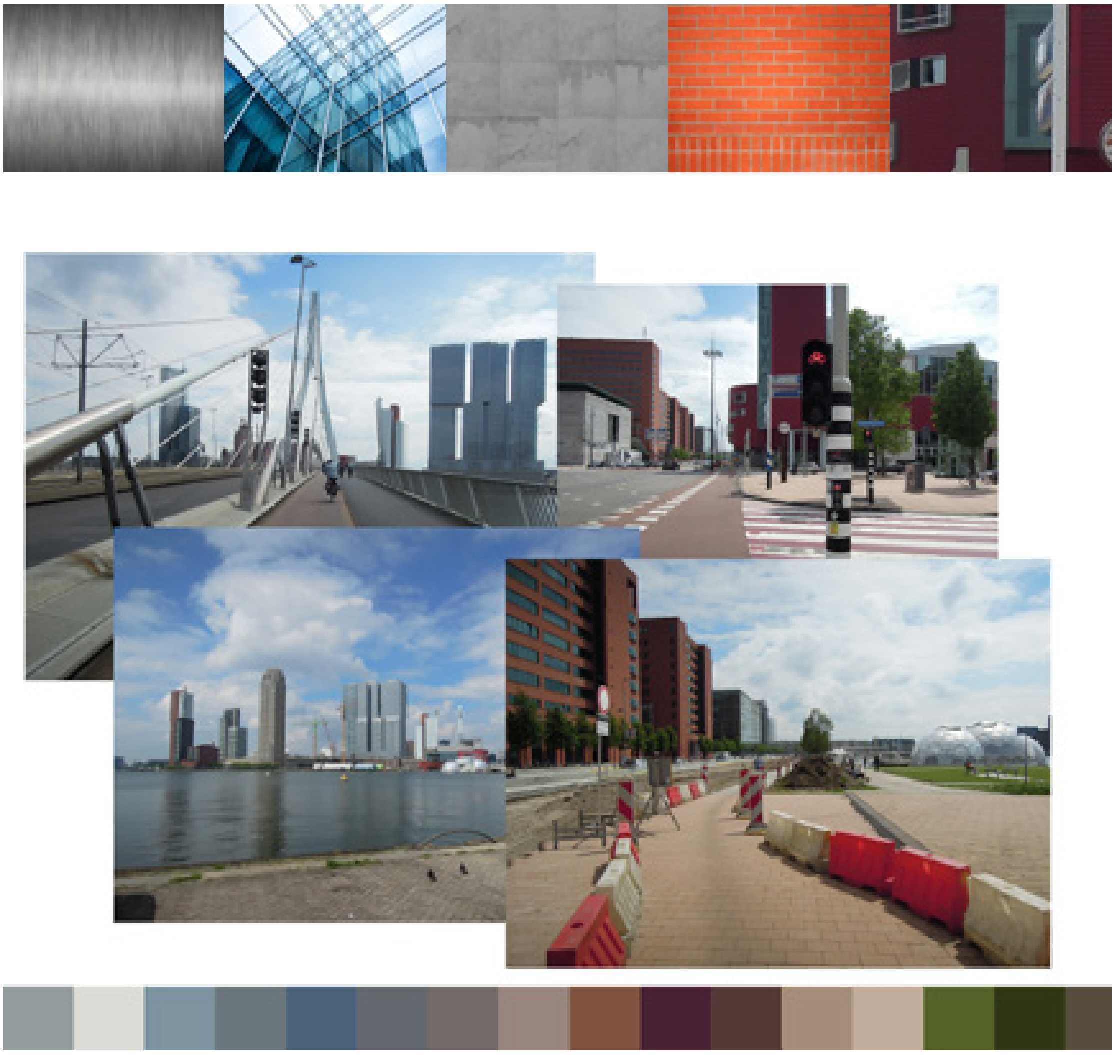


Figure 4.11: Sphere collage and colour palette Posthumalaan and Erasmusbridge

4.2.2 Schiedamsedijk and Coolsingel

Coolsingel is one of the most important streets of Rotterdam and used to be a canal. Since 1913-1922 this canal is filled to make room for the cars. Unfortunately, almost every building was bombed during the Second World War, so Rotterdam has to build new buildings along the Coolsingel (Spaan & Waag-Society, 2015). Today, this is one of the busiest streets of Rotterdam, with lots of shops, restaurants and public services. The street has a large diversity of buildings and building use, many openings and doors (around 10-14 doors per 100m) and many details on street level. The route is inviting and much is happening on street level. Coolsingel has more the intention to go and stay, than to move trough (Gehl, 2010).

Schiedamsedijk is the street between the Erasmusbridge and the Coolsingel. This street has a mixture of medium and larger buildings, which have different functions in use; business, shops and living. The route provides less liveliness in detailing of buildings, has some passive façades but has more trees and green than the Coolsingel, which makes the street more friendly and pleasant to move trough. The 'less' detailing of buildings refers to the post-war building style combined with a mixture of post-modernistic architecture. Most of the buildings along the Schiedamsedijk are built of red-brown brick, but Coolsingel has a large variety of building materials and styles (concrete, brick, metals and glass). At eye level many warm brown tints occur, which are varied with some cool blue tints. The trees provide a subtle green contrast with the buildings during summer. These streets can use warmer tints to appear less cold during colder days in winter.

Figure 4.12: Sphere collage and colour palette Schiedamsedijk and Coolsingel

4.2.3 Goudse Rijweg and Boezemweg

These street are partly from around 1900, but large parts are bombed or rebuild after the Second World War (Spaan & Waag-Society, 2015). This style transition is very visible in the variation of buildings. The buildings from before the war are built with dark brown bricks, have a lot of detailing on façades and differ in size and shape. The houses built during the period of 1980-1990 are generally more sober, have less detailing and are mainly built from sandstone-colour bricks.

The Goudse Rijweg is mainly a living street and has not much variation in other functions. The street is quite small and has a lot of front doors (around 15 per 100m). The street life is quite active and friendly (Gehl, 2010), but feels more relaxing than the busier Coolsingel for example. It has few blind or passive units, but detailing and material use are not varied and of low quality.
The Boezemweg has more variation in functions (living, retail), but has the same variation in building styles as the Goudse Rijweg. The street has a variety in unit size (between 10 or 15 units per 100m) and less passive façades than Goudse Rijweg. The houses from before the 2nd World War are very diverse and have great detailing on street level. Post-war housing is very repetitive and sometimes almost blank in terms of detailing and building variation. The west side of the street contains many buildings from before the 2nd World War where the east side of the street contains more post-war buildings.

Brown tints are the dominant colours in these streets, sometimes contrasted with some red tints or green from trees scattered along the streets. The general colour is quite sober and can use some variation of contrasting colours to make these streets more lively and friendly (Gehl, 2010).

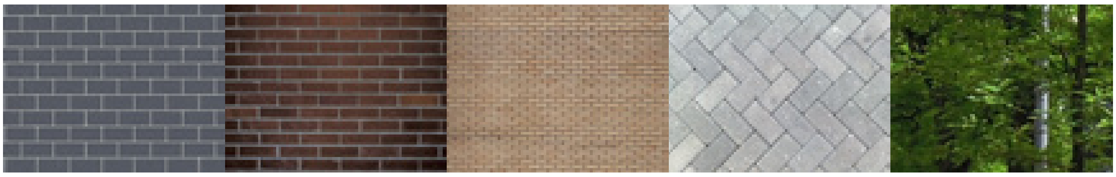


Figure 4.13: Sphere collage and colour palette Goudse Rijweg and Boezemweg

4.2.4 Bergweg

This street has the most pre-war remaining buildings, with a soft mixture between Neoclassic and Art Deco in a minimal way. The buildings originate from between 1880 and 1920 (Spaan & Waag-Society, 2015). The street has mixed functions such as living, retail and other commercial activities. Almost every corner has a shop and in between the corners are houses with a friendly atmosphere (10-14 doors per 100m). The street does not have many blind façades and is lively and interesting because the detailing on the façades (Gehl, 2010).
The main colour palette consists of warm brown tints, combined with some lighter yellows and whites. Trees form a lively contrast between the yellow and brown tints. Colder tints may be used in order to provide a cooler palette during warmer days.

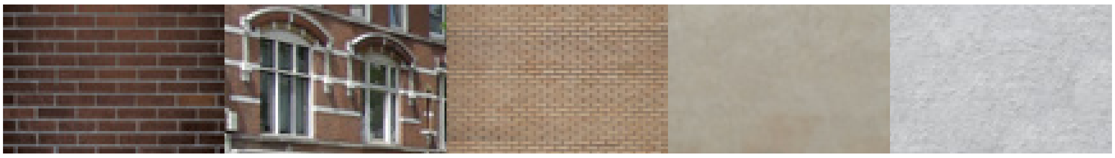


Figure 4.14: Sphere collage and colour palette Bergweg

4.2.5 Conclusion psychological influences

Parts of the routes are decreasing thermal perception levels through bad or blank psychological influences along the route. Posthumalaan has fewer doors per 100m, which can make this part of the route less exciting. Schiedamsedijk could use warmer tints for winter situations. Goudse Rijweg has a few blind façades and low building variation. Goudse Rijweg and Boezemweg are characterised by sober colour use. The east side of the Boezemweg has a very repetitive building style. Bergweg is quite good in terms of sphere, but could use a colder colour palette during warmer situations. The Coolsingel and Erasmusbridge are the only routes without psychological influence problems for cyclists. These two routes are vibrant, provide much to see and the buildings along the Coolsingel consist of much detailing and many doors per 100m. The map of figure 4.15 shows the problematic spaces for psychological influences on thermal perception.

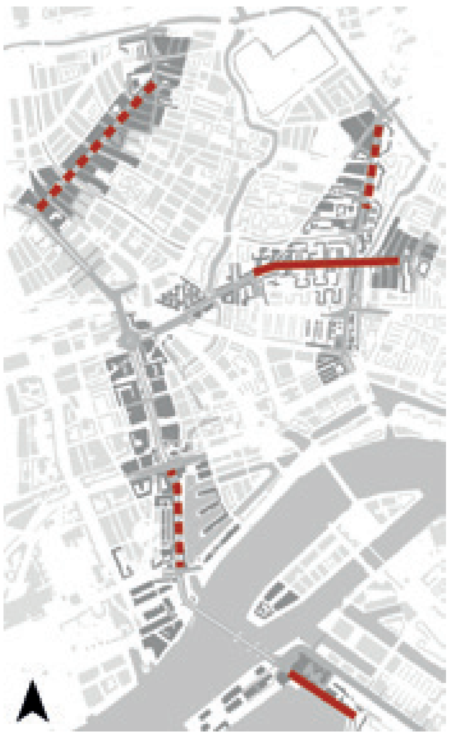


Figure 4.15: Psychological influences conclusion map

5. Problematic spatial configurations

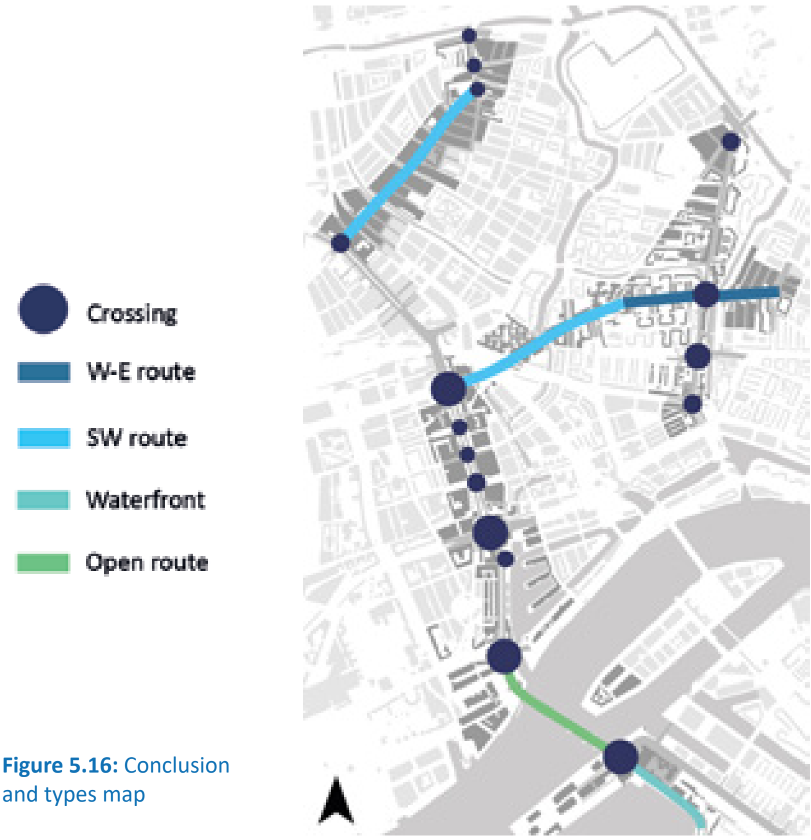
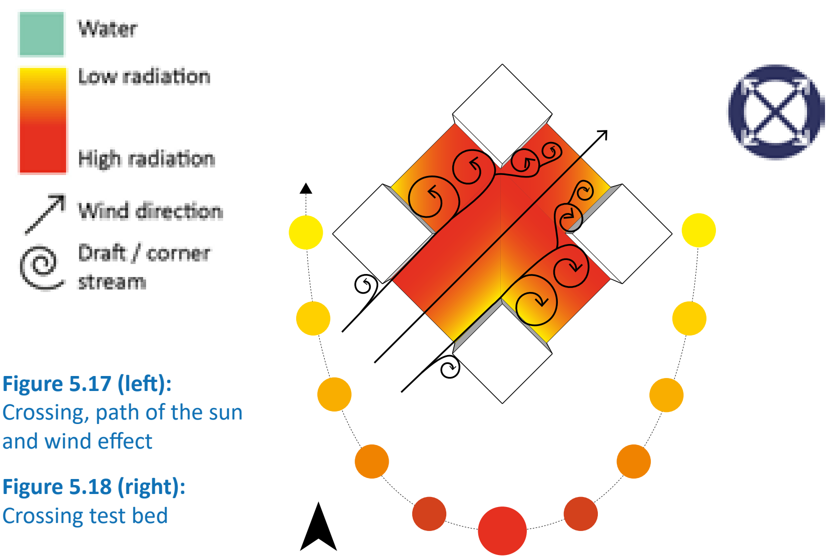


Figure 5.16: Conclusion and types map

This chapter aims to answer: (SQ3) Which spatial configurations could be identified as problematic on the found uncomfortable routes?
Subchapter 4 concluded that the influence of precipitation is the same in all problem routes, which forms a reason to draw the problem streets equivalent in the effect of precipitation. Although the precipitation is equivalent in all streets, shading and wind patterns are not equal in these problem streets (which also affects precipitation in combination with wind). If all problem zones and spots are superimposed, similarities and differences can be found. Figure 5.16 shows these layered problems. Layered problems could mean that multiple factors are influencing the thermal perception of a cyclist.

The problematic spatial configurations can be separated in 5 types:

- **Crossings:** Are one of the most problematic types, because most of them have all of the problems combined; hard wind from SW direction, too much shade in winter and less shade in summer (figure 5.17). A crossing is a place to stop and wait for other traffic. Cyclists are exposed for a longer time to uncomfortable weather conditions. This type is located in densely built urban areas. Figure 5.18 displays the generalized test bed of the crossing.



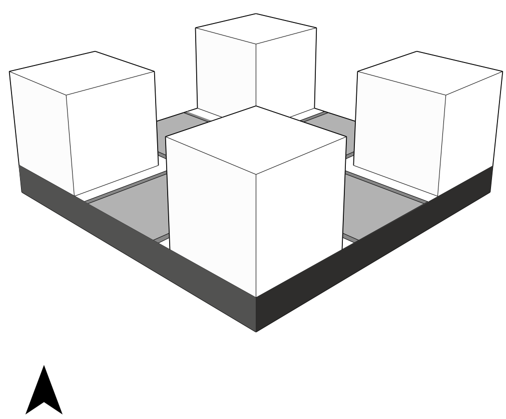
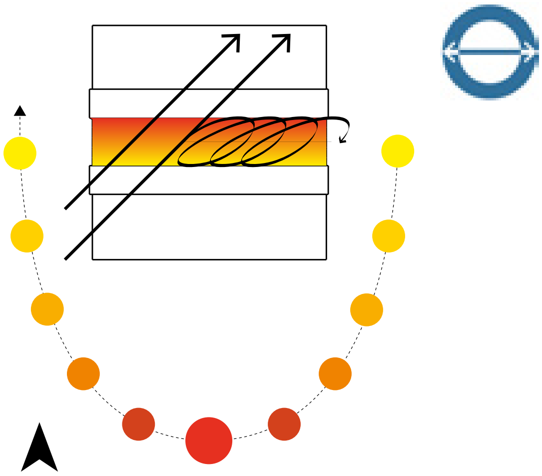


Figure 5.17 (left): Crossing, path of the sun and wind effect

Figure 5.18 (right): Crossing test bed

- **West – east routes:** The more a street faces this direction, the worse microclimatic conditions are. In summer less shade occurs on the streets, and in winters there is too much shade. Wind is semi-problematic in these streets, however in some situations SWW or westerly winds occur and form less comfortable thermal conditions for cyclists (figure 5.19), but these routes are less problematic for wind than the SW oriented streets. Figure 5.20 displays the generalized test bed of west - east routes.



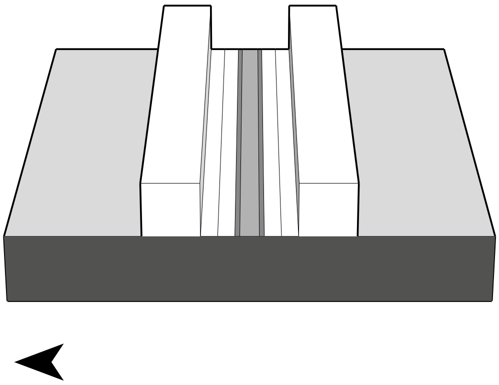
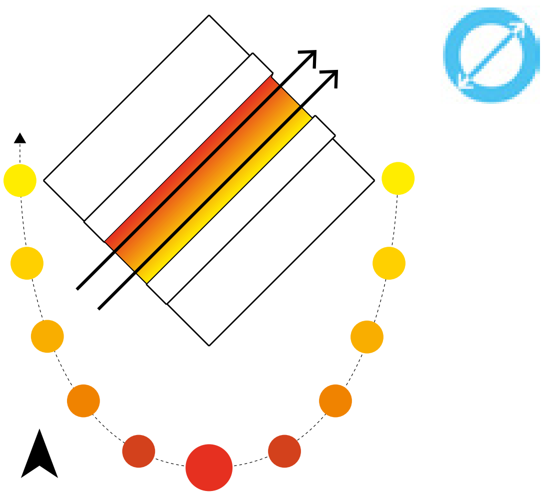


Figure 5.19 (left): East-west route, path of the sun and wind effect

Figure 5.20 (right): West - east route test bed

- **Southwest routes:** The more a street faces Southwest, the more wind is able to blow through these streets (figure 5.21). Winds from the southwest are dominant in Rotterdam and create thermal discomfort of cyclists especially during colder days (under 15 °C). If a cyclists needs to ride in southwest direction, he or she is affected by hard wind. This affects thermal perception (by heightened metabolic rate) negatively during warmer days or positively during colder days. These streets are semi-problematic for shortwave radiation. During summer days, half of the street is covered with shade (south side of the street), during winter days half of the street is exposed to the sun (north side of the street). Figure 5.22 displays the generalized test bed of the southwest routes.



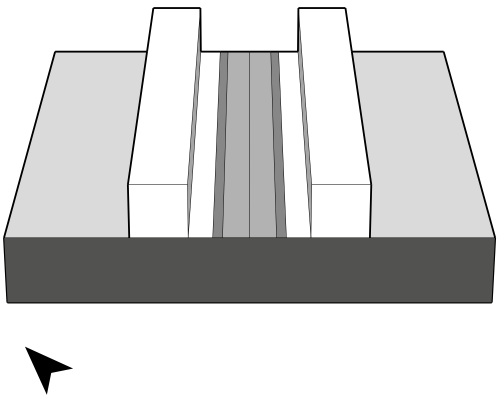
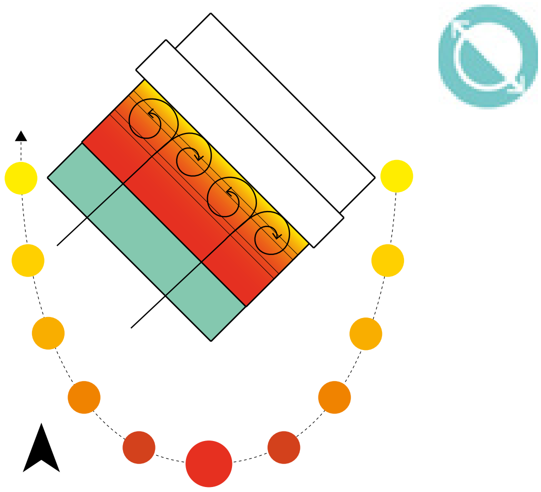


Figure 5.21 (left): Southwest route, path of the sun and wind effect

Figure 5.22 (right): Southwest route test bed

- **Waterfront routes:** The more a street is open, the more the weather is free to worsen thermal conditions of cyclists. Less shelter from wind makes it uncomfortable to cycle and creates more convection and resistance. These routes have less shade during warmer days and wind direction deviates during these warmer days. Therefore are these types of streets problematic in summer. During colder days hard winds cool people down and these winds could surprise people at corners at the ends of open streets, which makes these streets also problematic in winter (figure 5.23). Figure 5.24 displays the generalized test bed of the waterfront routes.



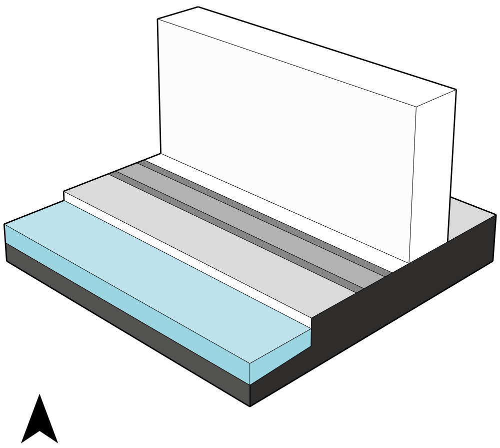
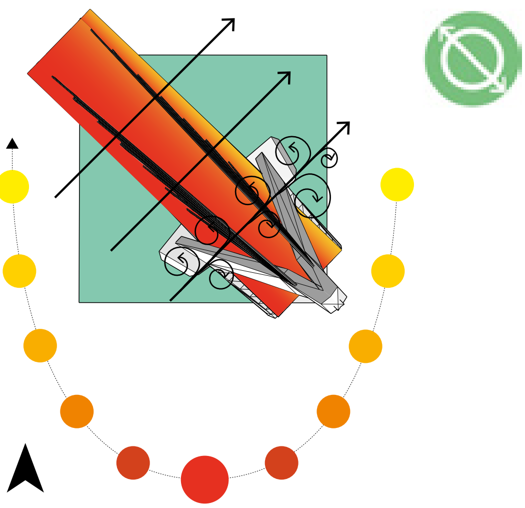


Figure 5.23 (left): Waterfront route, path of the sun and wind effect

Figure 5.24 (right): Waterfront route test bed

- **Open routes:** During warmer days, cyclists are fully exposed to the sun all day, but are slightly cooled by the wind. The Erasmusbridge is an example of this type of route. The bridge is sloped, which makes crossing the bridge more difficult, which results in higher metabolic rates for cyclist, thus lower thermal comfort levels during warmer days. Wind forms thermally uncomfortable conditions for cyclist when colder days occur. Cyclists are not protected against wind, precipitation and shortwave radiation (figure 5.25). Figure 5.26 displays the generalized test bed of the open routes.



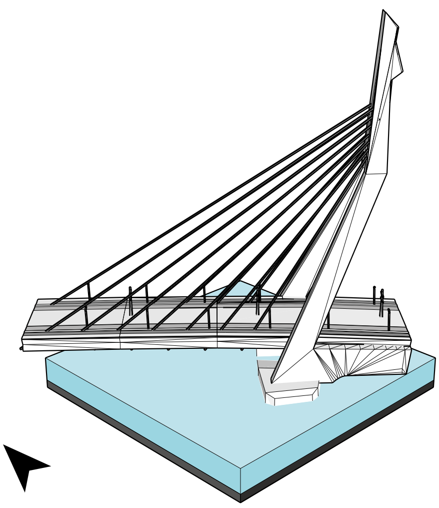


Figure 5.25 (left): Open route, path of the sun and wind effect

Figure 5.26 (right): Open route test bed

6. Design preconditions

This chapter aims to answer the following question; (SQ4) which conditions must be considered while designing solutions for the problematic spatial configurations?
All important aspects of chapter 3, 4 and 5 are taken into consideration to set the preconditions for new design solutions. These preconditions are the elements which are already there or should be improved in order to provide a valuable product for the university and the municipality of Rotterdam. In order to set an equal base of evaluation, an assessment matrix is used (as described in the methodology chapter 2.3). The assessment matrix is built on basis of preconditions/criteria. These criteria of the assessment matrix are categorized in wind, shortwave radiation, precipitation and general/safety categories.

6.1 Wind criteria

Wind protection or diversion is needed to improve the thermal perception of cyclists during colder days (below 15 °C) or if hard winds are combined with precipitation. Harder winds are creating more convection on cyclists. The more warmth is lost by convection, the lower thermal perception of a cyclist is. Wind is a problem during colder days, but helps cyclists to cool down during warmer days (above 24 °C). Therefore **wind admission** is needed during warmer days. Wind creates convection on cyclists and carries away the warmth and sweat from the skin. This effect influences thermal perception positively of cyclists (Brown & Gillespie, 1995; Lenzholzer, 2013).
Creating more or **less resistance** on cyclists is another effect wind has. When a cyclists rides against the wind direction, he or she will experience more resistance. This extra resistance increases the metabolic rate of cyclists. During warmer days, this increase of metabolic rate causes a negative effect on thermal perception. During colder days this increased metabolic rate creates a positive effect on thermal comfort levels of cyclists (Brown & Gillespie, 1995; Lenzholzer, 2013). Thus, during warmer days wind admission is needed to comfort cyclists, but extra resistance is not desired.
Tailwinds could be used in the design, to optimize the thermal perception of cyclists. Cyclists could be propelled by using the force of the wind. This will lower the metabolic rate and also creates more convection during warmer days. During cooler days tailwinds are less favoured than for warmer days, because they diminish thermal perception when winds are combined with precipitation, such as rain in the face (Böcker, 2014; Böcker & Thorsson, 2014).

6.2 Shortwave radiation criteria

Shading when temperatures are **higher than 24 °C** is required, because the probability of cycling decreases above these temperatures (Böcker, 2014). Shading can increase the thermal perception of cyclists during these warmer days (Brown & Gillespie, 1995; Klemm, Heusinkveld, Lenzholzer, & van Hove, 2015; Lenzholzer, 2013). Shading is not creating lower air temperatures, but minimizes the effect direct sunshine has on cyclists.
Shading is not needed if temperatures are below 15 °C (Böcker, 2014; Böcker & Thorsson, 2014). Therefore the criterion **no shading** for temperatures **under 15 °C** is needed to increase thermal perception of cyclists. The lower temperatures are, the more sunshine is needed to warm up the bodies of cyclists during colder days (Brown & Gillespie, 1995; Lenzholzer, 2013). However these criteria might positively influence thermal perception of cyclists, they could form dangers or shortcomings for cyclists or others. For example **light intrusion** on street level or inside buildings could be minimized when large panels or screens are blocking the sun (Lenzholzer, 2012, 2013). Sunlight also has positive effects on people’s perception of the environment. When people are more exposed to the sun, their serotonin levels increase, which leads to more pleasant emotions during their trip (Lambert et al., 2002), thus higher thermal comfort. Lower serotonin (against depression) and vitamin D (against skeletal and

muscle complaints) are measured by people which are less exposed to sun light (Lambert et al., 2002). This means that people outdoors and indoors need as much light as possible.
Design solutions might create dangerous **glares** when they are highly reflective. This could blind cyclists or motorists during their trip and bring them in dangerous situations. Different materials or coatings could lead to more diffuse or less bright glares of objects (Erell, Pearlmutter, Boneh, & Kutiel, 2014; Lenzholzer, 2013).

6.3 Precipitation criteria

Cover from direct impact of precipitation is important during colder conditions. Rain negatively effects the thermal perception of cyclists during these conditions. If temperatures are higher, precipitation has a more positive effect on cyclist's thermal perception. Precipitation cools down cyclists by direct impact and through evaporation of the fallen precipitation (Brown & Gillespie, 1995; Lenzholzer, 2013).

6.4 Safety & general criteria

This section of the assessment focusses on the general and safety criteria, conditions we perceive as 'normal' or take for granted while cycling.

There are two types of safety: objective safety and subjective safety. Objective safety is 'measurable' safety for cyclists and could be measured in terms of the number of bicycle-related incidents per million inhabitants. Subjective safety refers to how individuals perceive safety, which is measured in terms of the safety experience of cyclists. These two types of safety can both correspond with and differ from one another (Aldred, 2016; Heinen, Van Wee & Maat, 2010). Subjective safety is perceived when dedicated bicycle facilities are present. Objective safety is perceived by using physical measures. An example of such a physical measure are **wide enough paths** for cyclists, by roads with speeds over 40 km/h. Wide enough depends on the situation; the minimum width is 1,50m, but should be larger if parking spaces are next to the cycling path (at least 2,10m). Or if a pavement is next to the cycling path, a safety zone (to not scare pedestrians by sudden passing cyclists) next to the cycling path should be incorporated. Which means a cycling path should be at least 2,10m wide (de Groot, Ligtermoet, Partners, & Crow, 2006). Taken into account that cyclists perceive their environment better when riding accompanied (Böcker, 2014), the minimal path width should be 2,5m (de Groot, Ligtermoet, Partners, & Crow, 2006).

Also **sight or visibility** of cyclist should be enough to travel safely and comfortable. For cyclists who ride with a speed of 20 km/h, this sight should be 22 – 30m (de Groot et al., 2006). As well the cyclist should also have a free sight around and the cyclist itself should be seen by other traffic.

Other (general) criteria can be important for the municipality or a client. Three criteria are technical feasibility, (estimated) costs and maintenance. **Technical feasibility** depends on how realistic a solution is. If a solution needs more research or if it is not cost efficient to build at this moment, the technical feasibility value is lower. If many materials are needed, or expensive materials are needed to construct a solution, the **costs** will be higher. The design solutions scores lower if the costs are higher. **Maintenance** depends on how much a certain design solution costs after being built. For example the use of green needs more care and maintenance than a glass roof.

All the criteria are collected in one table which is shown on the next page (figure 6.1). In the following chapters these criteria form the spine of decision making for which principles are best and could be used for the integrated solutions.

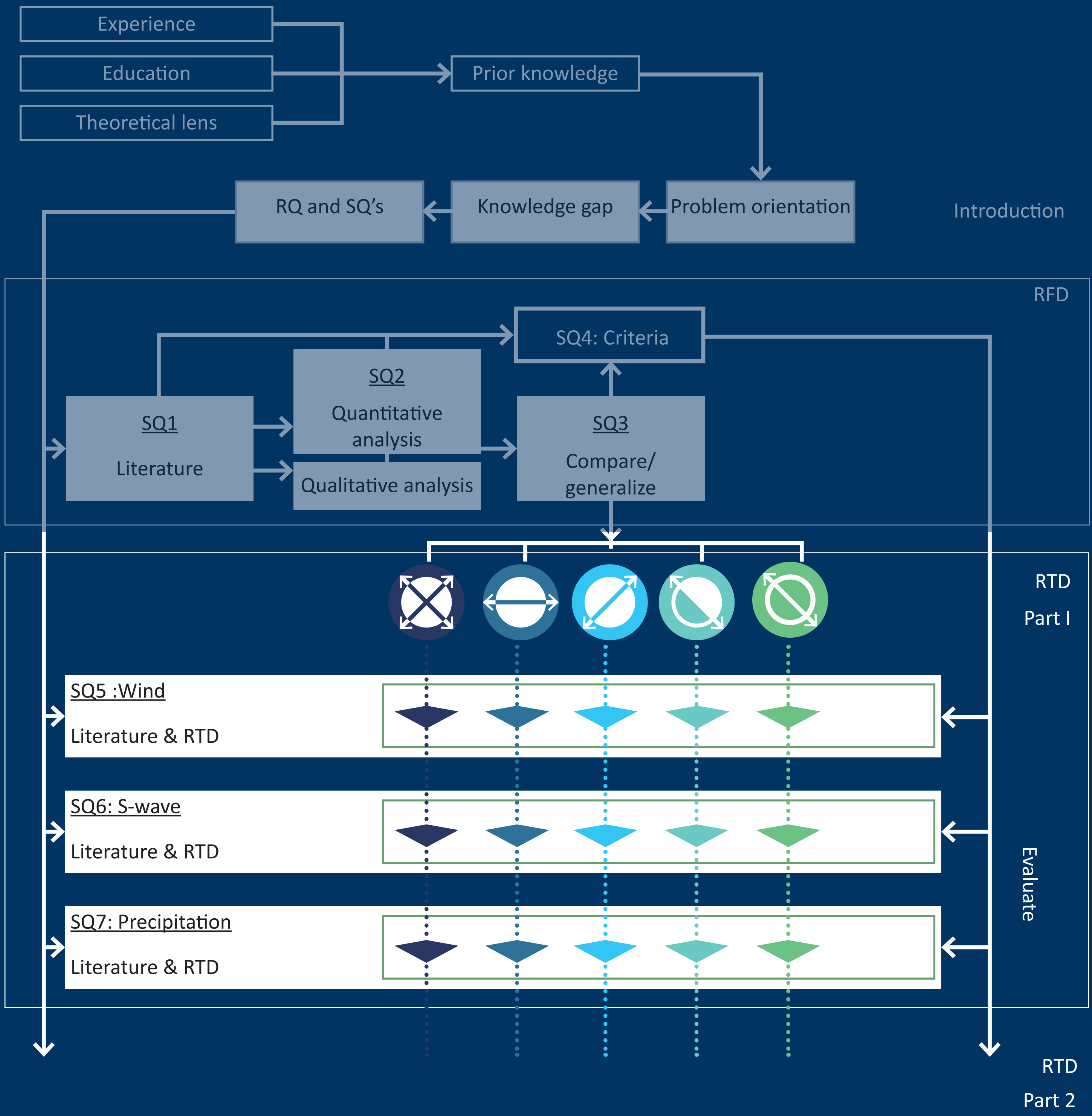
Solution/criterion	**1**	**2**	**3**
Wind			
Wind protection/diversion			
Wind admission (warm cond.)			
Tailwind			
Less resistance			
Shortwave radiation			
Shading temp. ^ 24 °C			
No shading under 15 °C			
Light intrusion			
No glares			
Precipitation			
Cover direct impact			
Safety/General			
Wide paths			
Visibility for/of cyclist			
Technical feasibility			
Costs			
Maintenance			
TOTAL SCORE			

+ + = Very good
+ = Good
0 = Neutral
- = Bad
- - = Very Bad

Figure 6.1: RTD assessment matrix

Research Through Design Part 1

The previous part of this thesis provided 5 test beds in order to design solutions for a better thermal perception of cyclists and an assessment matrix to evaluate the upcoming design solutions. RTD part 1 forms the first design iteration in the Research Through Design method. This part focusses on finding possible design solutions to improve the thermal perception of a cyclist coping with wind (SQ5), shortwave radiation (SQ6) and precipitation (SQ7).



Experience
Education
Theoretical lens
Prior knowledge
RQ and SQ's
Knowledge gap
Problem orientation
Introduction
RFD
SQ4: Criteria
SQ1
Literature
SQ2
Quantitative analysis
Qualitative analysis
SQ3
Compare/ generalize
RTD
Part I
SQ5 :Wind
Literature & RTD
SQ6: S-wave
Literature & RTD
SQ7: Precipitation
Literature & RTD
Evaluate
RTD
Part 2

7. Solutions for wind problems

This chapter describes possible solutions to tackle wind problems in order to improve the thermal perception of cyclists (SQ5). All five test beds are used as a basis to design new solutions coping with wind problems. The assessment matrix of chapter 6 is used to evaluate the design solutions.

7.1 Crossings

The first solution (figure 7.1) is a very simple solution, where an awning is used to redirect downwash winds. This awning can be folded during warmer days, so the wind is able to reach the street and to cool down the cyclists. The solution is one of the cheaper solutions and does not create disturbance in the visual field of the cyclists to other traffic and the other way around. Although it functions well for redirecting downwash winds, it does not give solutions for corner streams. The awnings also do not provide tailwinds for cyclists, but the awnings do decrease resistance and dangerous downwash winds.

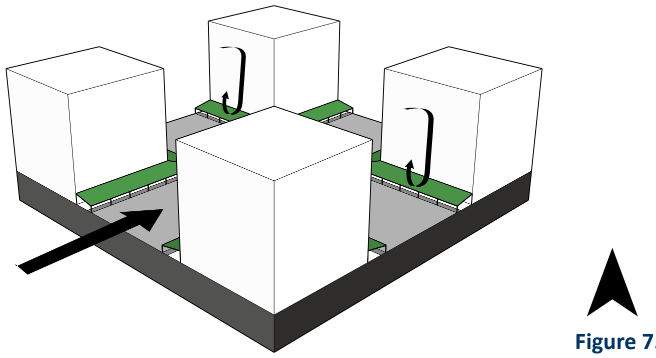


Figure 7.1: Downwash preventive awnings

The second solution (figure 7.2) uses the principle that wind blows faster at higher altitudes (Landberg, 2016). Therefore winds should be minimised at higher points, before they are able to downwash and hit cyclists. In the second solution, awnings are used to redirect wind not downwards, but away from the building. Higher (and faster) winds do not reach the cyclists. During warmer days these awnings could be folded down to allow cool winds on pedestrian and cycle paths (figure 7.3). Not all winds are redirected, even though the fastest winds are redirected. The wind facing buildings are equipped with a larger amount of wind rederecting awnings, where the less wind catching buildings are equipped with less wind redirecting awnings. The maintenance of these awnings is more expensive than the scaffolding of the first solution, because maintenance should be done at heights where a movable platform is mandatory.

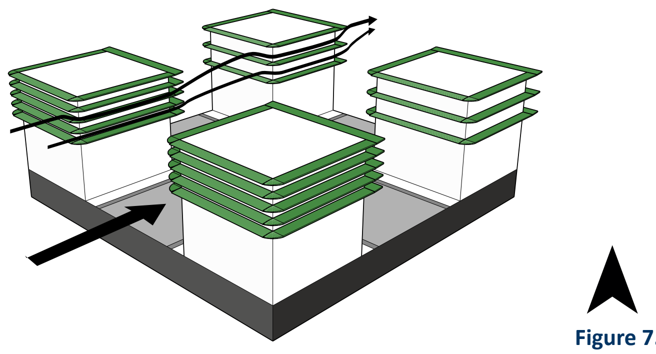


Figure 7.2: Flexible awnings for redirecting wind, deployed

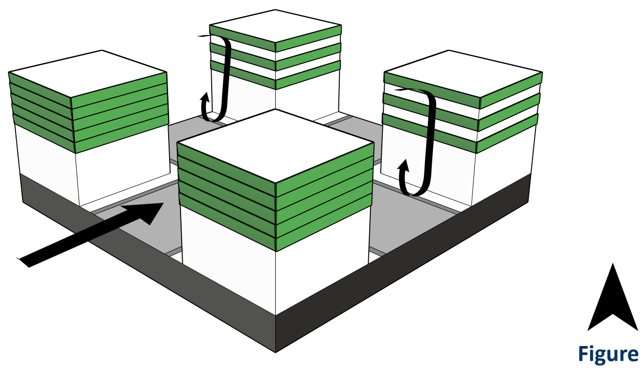
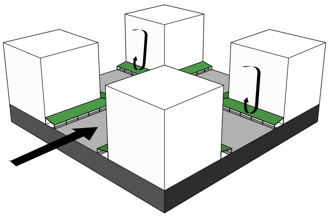
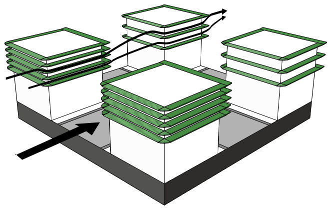


Figure 7.3: Flexible awnings for redirecting wind, folded

Test bed	 Downwash preventive awnings	 Flexible awnings for redirecting wind
Wind		
Wind protection/diversion	+	+
Wind admission (warm cond.)	0	+ +
Tailwind	- -	- -
Less resistance	+	+
Safety/General		
Wide paths	+	+ +
Visibility for/of cyclist	0	+ +
Technical feasibility	+ +	+
Costs	+ +	0
Maintenance	+ +	+
Total score	**2nd**	**1st**

7.2 West - east routes

These west - east routes are semi problematic for wind, because the wind is not directly blowing in these streets. Therefore the funnelling effect which is a large problem in southwest oriented streets will not be present in west – east oriented streets. However this does not mean there are no wind problems for these streets. Depending on the height width ratio (H/W ratio) of these streets, certain problems occur; The generalized test bed of the west - east street has 12m high buildings and 20m wide streets. This leads to an H/W ratio of 0.6, which means winds are partly skimming over the buildings and partly dropping down the streets. The flow pattern created is called 'wake interference flow' and it creates spiralling winds through these streets if the wind is not parallel to the street (Brown & Gillespie, 1995; Lenzholzer, 2013). These streets do not have dangerous downdrafts or corner streams along the streets. Although wind is not creating dangerous winds along the route, this thesis focusses on improving the thermal perception of cyclists. Therefore eliminating winds in colder situations (under 15 °C) could help to improve their thermal perception. In summer or warmer situations (especially when temperatures are higher than 24 °C), wind should be able to blow through these streets to ventilate and cool down the environment.

The incoming wind during colder days is the main problem at west - east streets. These cold winds could be blocked by making the buildings higher or by narrowing the street profile. This can be accomplished by adding an awning to both sides of the street (figure 7.4). Less wind flows against the wind facing façades, thus the thermal comfort of cyclists and everybody on the street is improved by this simple intervention. The awnings do not require street space and also do not decrease visibility much, because the awnings are installed at roof level.

The second solution is using the same principle to narrow the street profile by adding a row of trees (figure 7.5). Trees are not as dynamic as the weather; during warm days these trees block cooling winds. Trees do also need more space around them to grow well. These downsides of trees cause a lower score for this design solution.

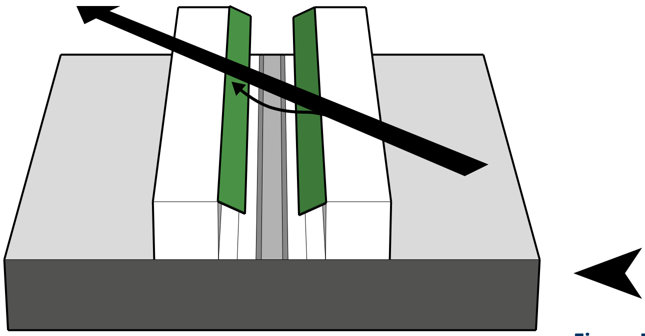


Figure 7.4: Narrowing the street profile at roof level

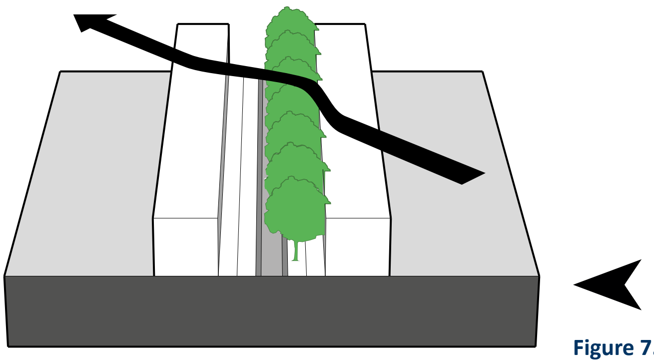


Figure 7.5: Tree lane at southern side of street

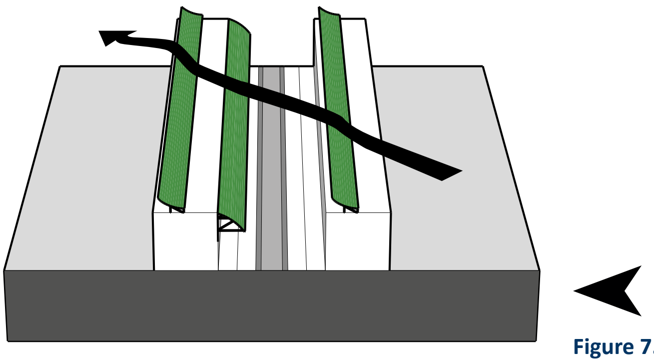
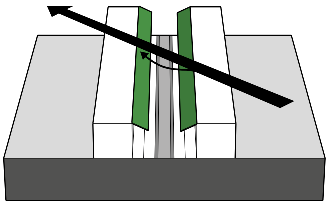
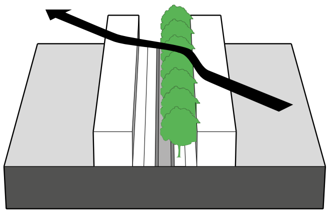
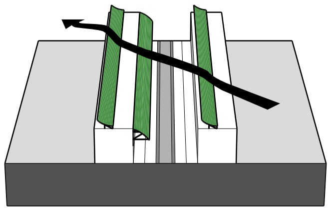


Figure 7.6: Adjustable awnings

The third solution (figure 7.6) is an answer to the problem of wind allowance during warmer conditions. Awnings are repelling wind during colder conditions, but guide wind to the street level to cool down the cyclists when warmer conditions occur. Cyclists experience less resistance when the awnings redirect the wind outside the street. Thereby do these awnings require little maintenance, are not very expensive and technically feasible. The path width is unaltered in this solution.

Test bed	 Narrowing the street profile at roof level	 Tree lane at southern side of street	 Adjustable awnings
Wind			
Wind protection/diversion	+ +	+	+ +
Wind admission (warm cond.)	0	- -	+ +
Tailwind	- -	- -	- -
Less resistance	+	0	+ +
Safety/General			
Wide paths	+ +	-	+ +
Visibility for/of cyclist	+	0	+
Technical feasibility	+ +	+ +	+
Costs	+	0	0
Maintenance	+	- -	+
Total score	**2nd**	**3rd**	**1st**

7.3 Southwest routes

Southwest is the dominant wind direction and if a street faces this direction, wind is perpendicular to the street. Although fast and strong winds might seem a problem for cyclists, these winds are not a problem for all cyclists; If one needs to drive against the wind, fast and hard winds are a problem. When a cyclist is cycling with the wind in his back (tailwind), he or she does have less resistance and/or is even pushed forward by the wind. Therefore resistance should only be diminished when someone needs to cycle against the wind direction, but not when someone has the wind in his/her back. It is necessary to eliminate the wind in colder situations (under 15 °C) and ventilate the street during warmer conditions (temperatures higher than 24 °C) to improve the thermal perception of cyclists (Böcker, 2014; Lenzholzer, 2013).

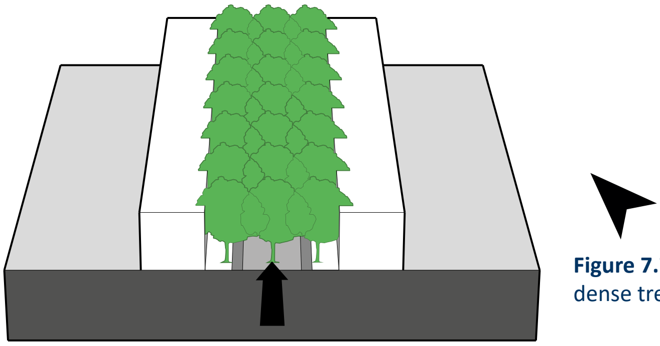


Figure 7.7: Evergreen dense trees

The first design option completely blocks the wind (figure 7.7), so wind is blocked during colder conditions. However, this is a desired effect in winter (only reached when evergreen trees are used), but this is not desired during warmer conditions. Wind should be able to blow through gently during warmer situations. The second solution is an opened version of the first solution (figure 7.8). More space is available between the trees. It enables wind to blow through the street, but does not reach high wind speeds anymore. In this case the trees do not take as much room as the first design solution, because fewer trees are planted to reach the desired effect.

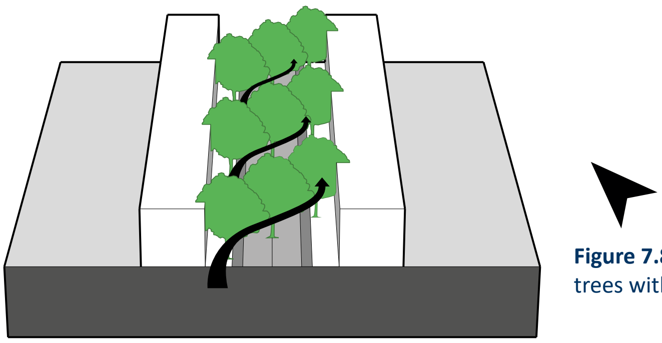


Figure 7.8: Evergreen trees with openings

The first two solutions only slow down wind, where the wind also could be used in the advantage of the cyclist. The third solution focusses on maximizing the benefits of wind for cyclists; tailwind for cyclists who are cycling from southwest to northeast direction and wind shelter for the cyclists who are cycling the opposite way. Parking spaces for cars or cyclists are planned in between the wind screens, so no space is lost. The third solution has the highest score, because it uses the wind and also effectively blocks the wind. The first solution with the tree packed street is the lowest scoring solution and should not be used.

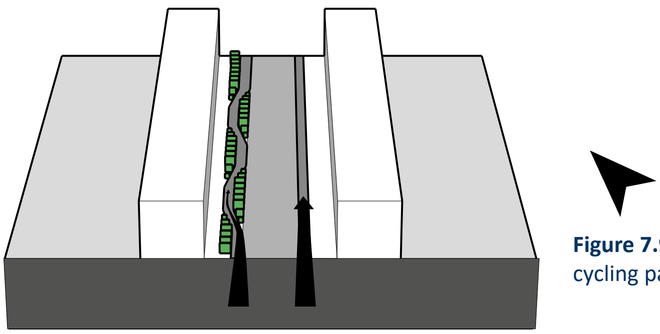
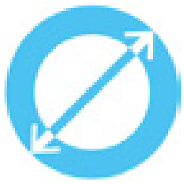
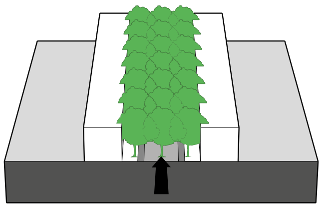
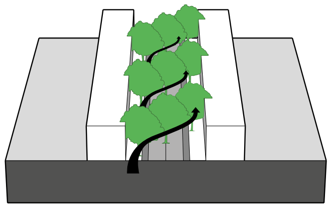
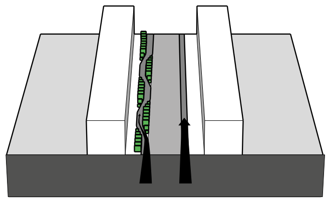


Figure 7.9: Tailwind cycling path

Test bed 	 Evergreen dense trees	 Evergeen trees with openings	 Tailwind cycling path
Wind			
Wind protection/diversion	+ +	+	+ +
Wind admission (warm cond.)	- -	0	0
Tailwind	- -	- -	0
Less resistance	+ +	+	+ +
Safety/General			
Wide paths	- -	-	0
Visibility for/of cyclist	-	-	0
Technical feasibility	0	+	+
Costs	-	0	0
Maintenance	- -	-	+
Total score	**3rd**	**2nd**	**1st**

7.4 Waterfront routes

The main problem for cyclists along waterfront routes is their exposure to all weather conditions. The harbour area and waterfronts provide a lot of space for wind to gain speed. Cyclists are exposed by hard winds from all directions. Waterfront routes are exposed to the wind from the side. The alternation of a few large buildings with the open spaces along the waterfront, creates turbulent areas for cyclists. The Kop van Zuid has a few high buildings with large dimensions, which creates lee sides but also fast corner streams. This change from lee side into corner stream may blow people from their bike or could cause dangerous situations where cyclists are blown onto the lane. These routes are one of the most problematic in case of the wind perspective, because all other typologies are more or less protected by buildings. To design a more thermally comfortable environment for cyclists, waterfront routes need to be designed differently. Side winds and corner streams should be diminished. Although cyclists could be protected by the wind, they also could be pushed by the wind to have the wind in their advantage.

The first solution is completely protecting cyclists from the wind by a tunnel made of glass and metal (figure 7.10). However, this might be an expensive solution, because these waterfront areas could be large and therefore the design intervention to implement such a tunnel would be of a too large size.

The second solution is using green to protect cyclists from the wind (figure 7.11). Dense green in the form of trees and shrubs is used to protect cyclists from side winds. Green façades and the tree canopy are used to slow down downdrafts from large buildings along the semi-open routes. But it is questionable if the green walls are very effective with these higher winds speeds.
Another, third solution focusses on the best, but minimalistic wind protection for cyclists (figure 7.12). Awnings are placed on the 1st floor height of buildings to protect cyclists from down drafts and a semi-permeable screen is placed along the route, to protect cyclists from side winds. It is one of the cheapest interventions, but it does not allow wind in the summer to cool down the street and also does not provide tailwinds.

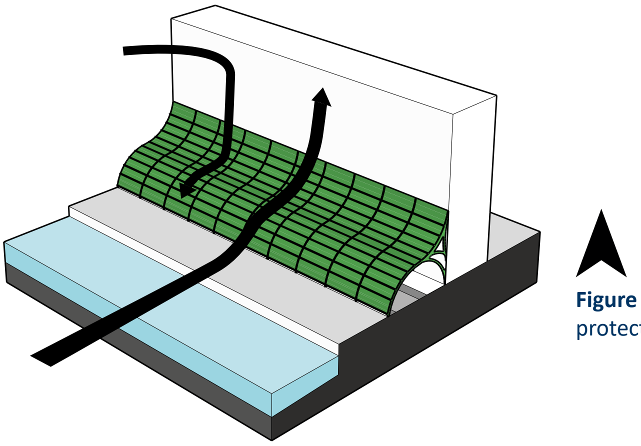


Figure 7.10: Complete protection

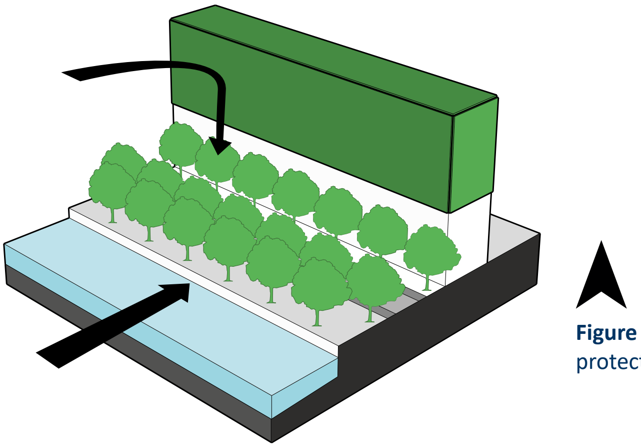


Figure 7.11: Green protection

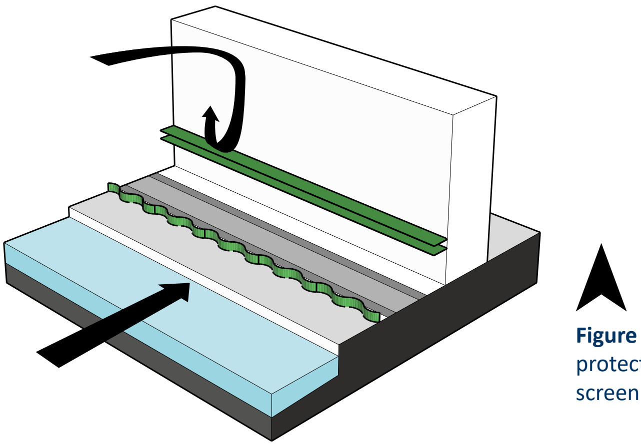


Figure 7.12: Simple protection awnings and screen on the first floor

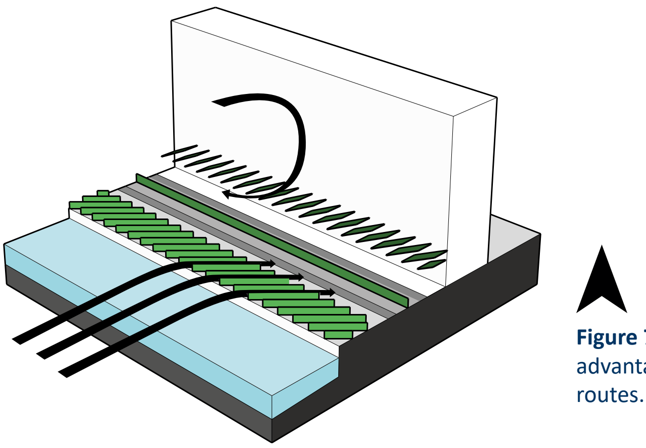
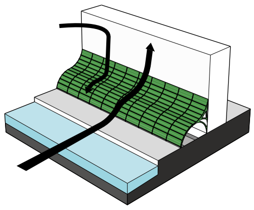
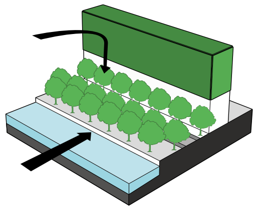
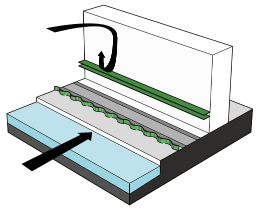
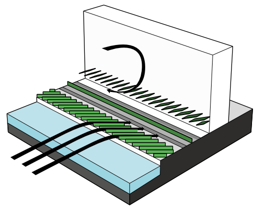


Figure 7.13: The tailwind advantage in waterfront routes.

Another solution needs to be designed To use wind in the advantage of the cyclist. The fourth solution uses screens with a smooth surface to propel cyclists in the right direction. A screen in between the two directions is used to prevent mixing winds. This is the highest scoring solution due to its ability to form wind in the advantage of the cyclists. However, it is advised to use translucent screens, otherwise the connection with the environment would be lost.

Test bed	 Complete protection	 Green protection	 Simple protection awnings and screens on first floor	 The tailwind advantage in waterfront routes
Wind				
Wind protection/diversion	+ +	0	+	+ +
Wind admission (warm cond.)	- -	0	-	+ +
Tailwind	- -	- -	- -	+ +
Less resistance	+ +	0	+	+ +
Safety/General				
Wide paths	+ +	+ +	+ +	+
Visibility for/of cyclist	+ +	+	+ +	+
Technical feasibility	-	+	+	0
Costs	- -	+	+ -	-
Maintenance	+ +	- -	+ +	+ +
Total score	**3rd**	**4th**	**2nd**	**1st**

7.5 Open routes

Cyclists that are driving on the bridge are exposed to all weather components. Wind has a lot of space to gain speed on the River Meuse. Cyclists crossing the Erasmus bridge are exposed to high speed winds (see chapter 4.3.2 ‘wind influence’). The resistance to ride on the bridge is also increased by the wind, which increases the metabolic rate. This heightened metabolic rate causes thermally uncomfortable conditions during warmer days.

The first solution diminishes the wind effects by placing large screens on the sides of the bridge (figure 7.14). These screens decrease the resistance of cyclists and protect cyclists from cold winds during colder days. However, during warmer days there is no wind to cool the cyclists. These screens also block tailwinds, which could make the crossing of the bridge more comfortable. Another negative factor is the sight of the cyclists; the screens cover a large part of the field of sight of cyclists. All other criteria are rated high (e.g. wide paths, no obstacles, technical feasibility, costs and maintenance).

The second solution also uses screens, which are open in the direction of movement (figure 7.15). In this way wind is deflected in the advantage of the cyclists. This difference creates tailwinds and wind admission during warmer conditions. The only sacrifice that must be made for this purpose is less space on the pedestrian path, resulting in less wide paths at the setbacks of the panels on the pedestrian path. The screens are blocking the beautiful view over the river Meuse and cyclists are also covered in the field of sight of car drivers and other traffic.

The third solution (figure 7.16) offers more sights on the Meuse and a better sight around, which increases the feeling of safety for cyclists and other traffic. Funnels are designed on the wind facing side of the bridge. These funnels are placed above a screen of 2,5m height and deform the wind in the desired direction. The propelling effect of the wind is large, because the wind is directly blowing through these funnels. This wind effect is a bit smaller on the other side of the bridge because traffic and the wind interventions create wake areas. Therefore the air inlets of the other driving direction (north) are placed on a higher level. These air

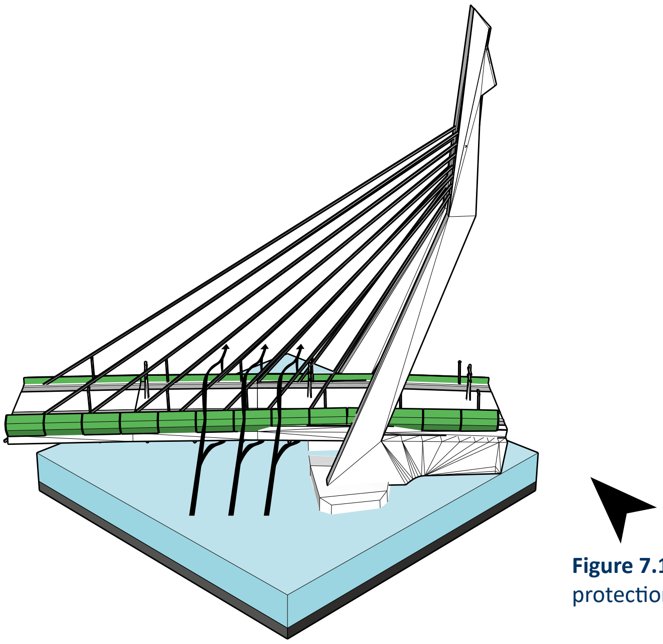


Figure 7.14: Wind protection screens

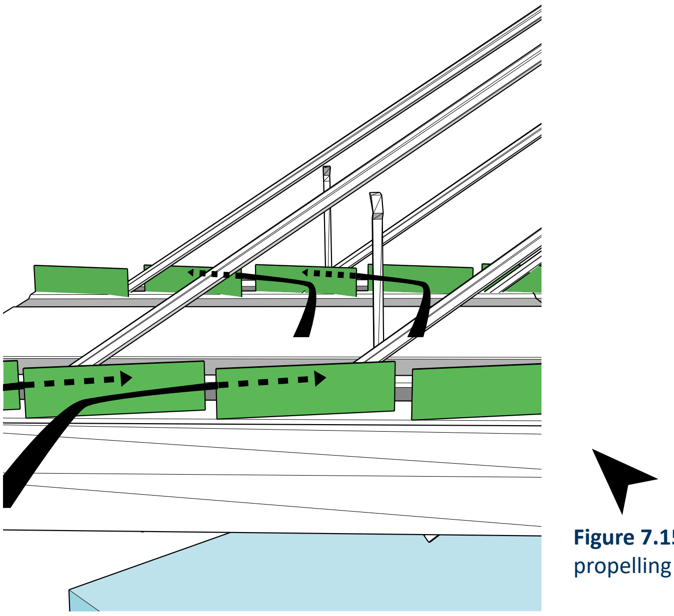


Figure 7.15: Cyclist-propelling screens

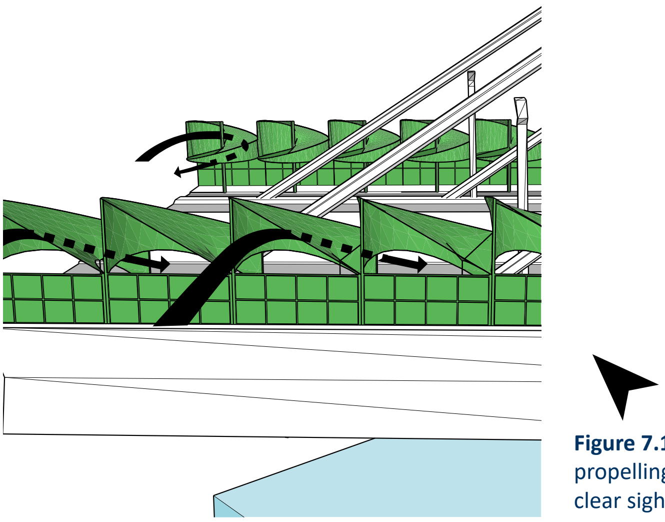
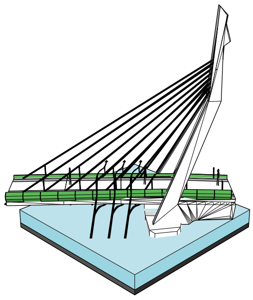
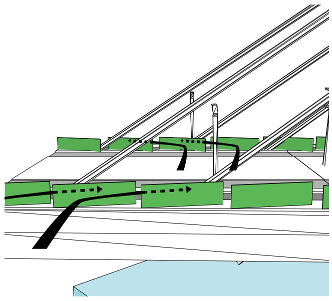
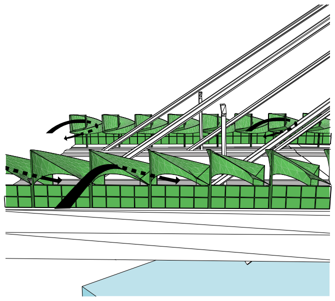


Figure 7.16: Cyclists-propelling vents with clear sights

inlets have the form of a volute, which compress air in a spiralling motion downwards the cyclists to push them forward. This solution scores maximum points on wind protection, wind admission, tailwind and less resistance, but are scoring lower in costs and malleability then the other design interventions.

Test bed 	 Wind protection screens	 Cyclist-propelling screens	 Cyclists-propelling vents with clear sights
Wind			
Wind protection/diversion	+ +	+	+ +
Wind admission (warm cond.)	- -	+ +	+
Tailwind	- -	+	+ +
Less resistance	+	+ +	+ +
Safety/General			
Wide paths	+ +	+	+ +
Visibility for/of cyclist	+ -	+ -	+
Technical feasibility	+ +	+ +	+
Costs	+ +	+	-
Maintenance	+ +	+ +	+ +
Total score	**2nd**	**1st**	**1st**

8. Solutions for shortwave

Shortwave radiation has a negative influence on the thermal perception of cyclists if the temperature is higher than 24 °C, but have a positive influence on their thermal perception during colder situations (below 15 °C). The following chapter is about coping with this duality (SQ6) to form design solutions for all five spatial types. Thereby, the sun angle and position of the sun are changing during the days and during the year. Two ways of solving shortwave problems are used in this chapter:

1. **Intercept** radiation before it reaches a surface by placing something in its path.
2. **Change the materials** and thus the absorption of sunlight. (Brown & Gillespie, 1995)

8.1 Crossings

The analysis of the shortwave radiation shows crossings as one of the most problematic spots in the city. In summer there is too much sun, which heats up cyclists. In winter there is too much shade, which cools down the cyclists. Thereby, cyclists have to wait for red lights or other crossing traffic and thus are exposed for a longer time to these uncomfortable weather conditions. Therefore, a solution is needed to improve the thermal perception of waiting and crossing cyclists.

The first option intercepts the sunlight before it reaches the cyclists, movable screens can be used to protect cyclists from the burning sun (figure 8.1). These screens can be folded when temperatures are not very high, to let the sun reach the cyclists.

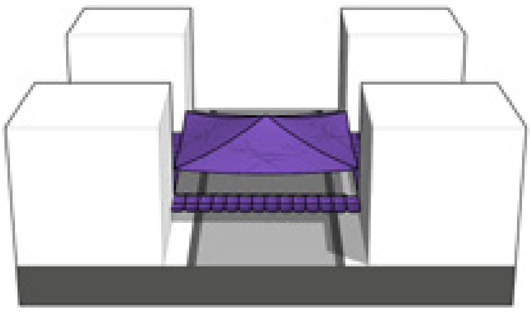


Figure 8.1: Movable screens above the crossing and waiting places

A second way to intercept incoming sun are trees or overhanging green branches/ pergolas (figure 8.2). This green covers the street during summer situations, but is open during winter situations. This natural solution might seem properly working, however it is not as dynamic as the weather is and therefore not very suited for colder summer days. Larger vehicles such as trucks will suffer while driving underneath the low hanging pergolas.

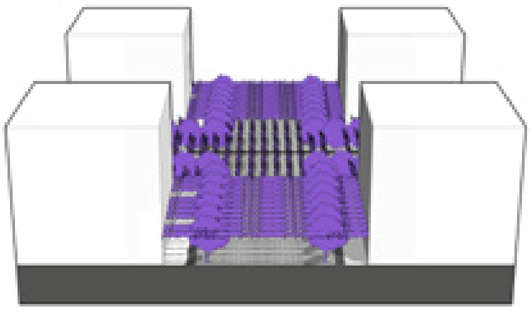


Figure 8.2: Trees and overhanging greenery

The next solution is focused on altering the colour of a material to reflect or absorb radiation, depending on the temperature. This reversible transformation between a specie between two forms, A and B, having different absorption spectra, induced in one or both directions by the absorption of electromagnetic radiation. This process happens photochemically or thermally and can be formed out of organic or inorganic compounds (Pardo, Zayat, & Levy, 2011). This technique is practiced for many forms, such as photochromic glasses.

The third and fourth solutions both use the principle of hybrid coloured materials (figures 8.3 and 8.4). Photochromic glass is used to form a good protection against the sun. This glass will change from fully transparent in colder days to shaded glass in warmer days. In this way a part of the incoming radiation is reflected in warmer days, thus the cyclists will receive less shortwave radiation. It is important to not fully close the roof of such a glass structure, because warmth is trapped underneath this roof and will cause a negative (too warm) effect on cyclists if it is not open (figure8.3). Also a less expensive solution can be designed to only cover the cycling paths with photochromic glass panels (figure 8.4). In this way cyclists who are traveling to the crossing or have to wait for red lights, are protected from the sun but are only exposed to the sun when they cross the street.

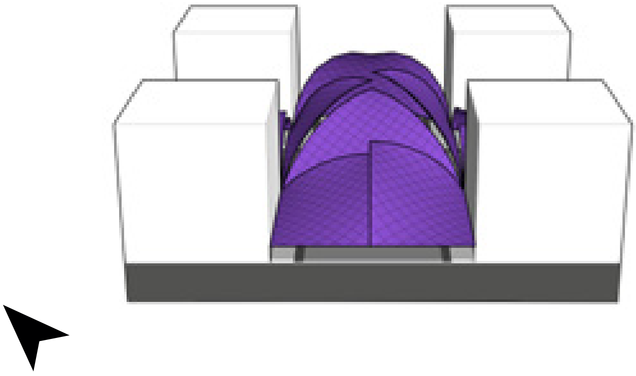


Figure 8.3: Photochromic glass dome

The excess of light is solved in the first three solutions, but the shortage of light during colder (winter) days is not. It could be more or less solved by catching the available radiation and reflecting it on the street. High points on buildings, which are not shaded by other buildings can be used to catch this radiation and reflect it to the place where it is needed. The last solution (figures 8.5 and 8.6) uses the simple solution of movable screens for summer/warmer situations, but then by alternating the angle of the screens and folding screens which cast shadow on the other screens. In this way, not the top side of the screens is sunlit, but the bottom. The bottoms work as reflectors with reflective plains which emit a diffuse light in the right direction. These reflectors follow the angle and altitude of the sun to have a maximum effect when needed in the winter. In summer situations, the sun is on a higher altitude and casts shadows on the streets.

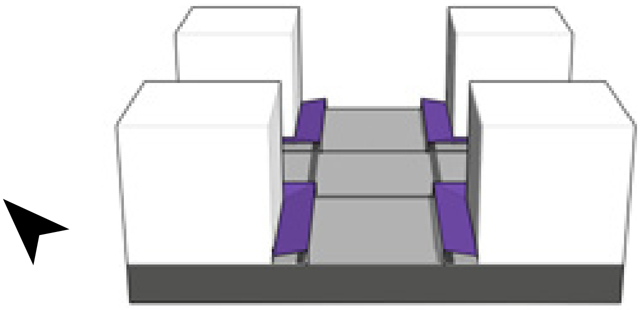


Figure 8.4: Simple photochromic glass intervention

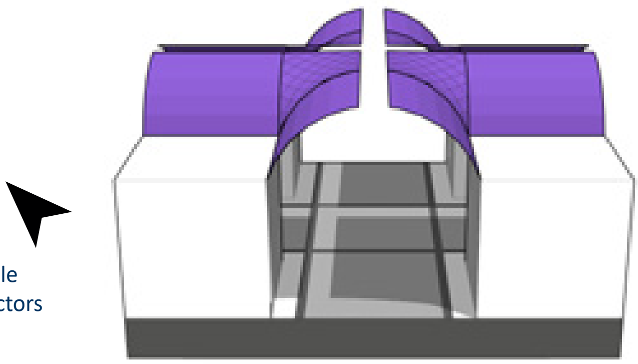


Figure 8.5: Movable awnings and reflectors summer situation

As seen in the matrix, the designs 4 and 5 are the best solutions. These solutions are malleable and not as expensive as for example solution 3. Solution 3 with the photochromic glass dome is maybe better in protecting cyclists from the sun in summer and allowing sun to them in winter. However, it does not use the available light in winter to reflect on cyclist, as solution 5 is doing.

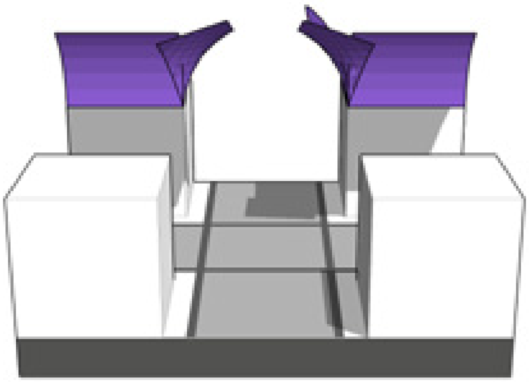
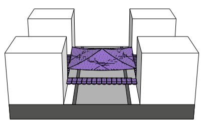
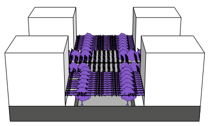
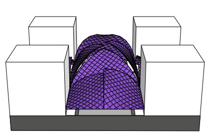
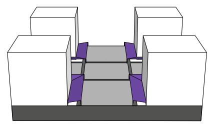
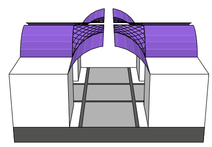


Figure 8.6: Movable awnings and reflectors winter situation

Test bed 	 **Moveable screens**	 Trees and overhanging greenery	 Photochromic glass dome	 Simple photochromic glass intervention	 Moveable awnings and reflectors
Shortwave rad.					
Shading ^24 °C	0	+ +	+ +	+	+ +
No shading under 15 °C	+	0	+ +	+ +	+ +
Light intrusion	0	0	+	+	+ +
No glares	+ +	+ +	0	+	+ +
Safety / Common					
Wide paths	+ +	0	+ +	+ +	+ +
Visibility for/of cyclists	+	+ +	+	+ +	+ +
Technical feasibility	+ +	+ +	0	+ +	0
Costs	+	+	- -	+	-
Maintenance	+ +	- -	+	+	+ +
Total Score	**2nd**	**4th**	**4th**	**1st**	**1st**

8.2 West - east routes

The analysis chapter highlighted these streets as the most problematic in case of more exposed spots and less exposed spots. This means that this street is radiated by the sun for the whole day and does not provide much shade for cyclists during the summer situation, but also does not provide much shortwave radiation during the winter situations. This leads to potentially too hot streets in summer days and too cold streets during winter days. One of these problematic streets is the Goudse Rijweg in Rotterdam. The biggest problem is created during winter, when the sun does not reach the street for a long period of the day.

The first solution focusses more or less on the existing situation's solution. Trees cover the street in the present situation (figure 8.8). Trees are good enough for shading a street during warmer days. Although this solution works for shading, it is not always open in situations where temperatures are under the 15 °C. These trees also need space to grow and this is a less beneficial aspect of trees.

The second solution (figure 8.9) uses movable screens to protect cyclists from too much shortwave radiation, but could be opened during days where temperatures are below 15 °C. This solution scores high because it is helpful in periods when needed. But the street is not occupied with shading trees when there is no need for shade. This solution is easy to construct and does not cost as much as planting trees and maintaining them.

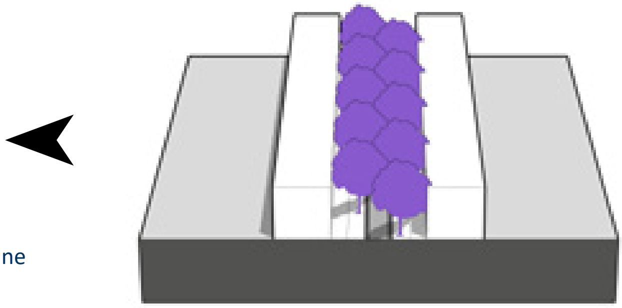


Figure 8.8: Tree lane shading

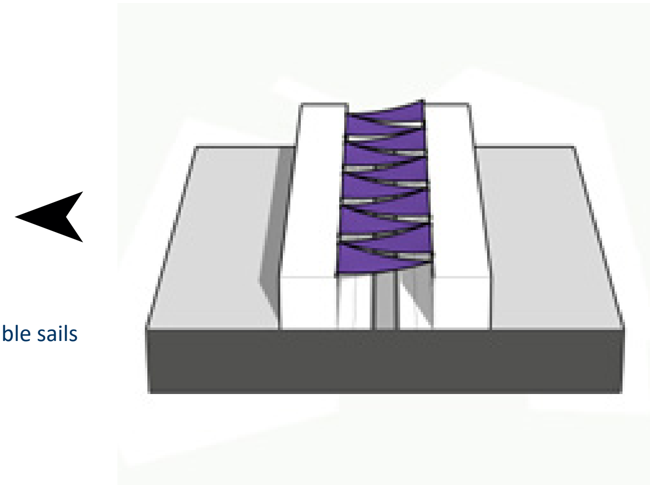


Figure 8.9: Movable sails

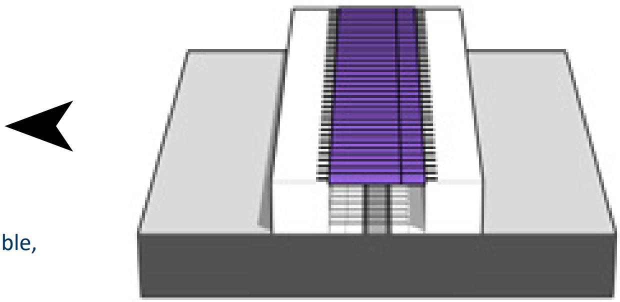


Figure 8.10: Movable, reflective screens summer

The third solution (figures 8.10 and 8.11) uses the available sun when there is fewer incoming shortwave radiation. During a part of the day, a part of the houses will be radiated but not the street itself. Moveable screens or reflectors could be used to guide the incoming radiation to the street to illuminate the street, but also to heat up the street during colder days. These screens could be turned in another position to block the sun during warmer days. Although this solution solves the radiation problem, it is a very expensive solution to install all these screens and keep them running throughout the year.

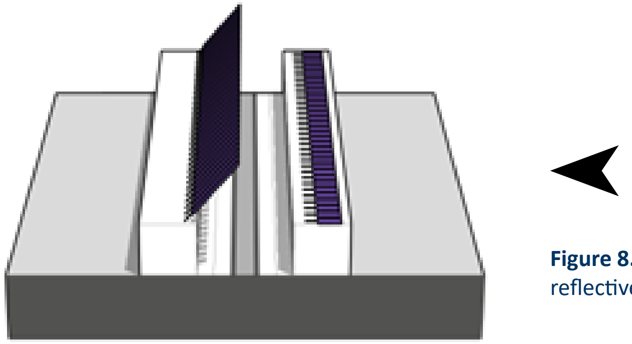


Figure 8.11: Movable, reflective screens winter

The fourth solution (figure 8.12) is an intermediate solution in shading for temperatures higher than 24 °C and having no shading under 15 °C. It is simpler to build then other solutions, but still quite expensive and does need maintenance. It has the advantage of having a lot of space on the street, because there are no big tree trunks or rooting places needed. This offers the municipality more room for other interventions on the streets and gives the cyclists a green tunnel to drive through. The green is not always open for temperatures under 15 °C, which is a downside for using this solution.

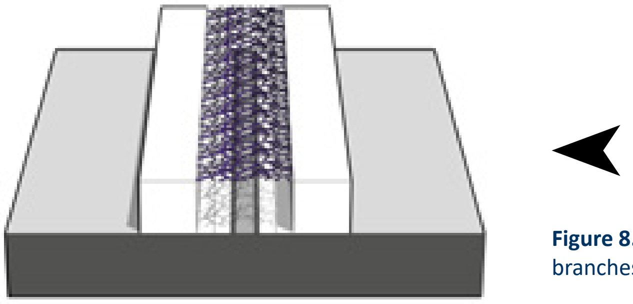
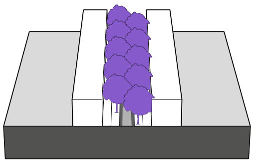
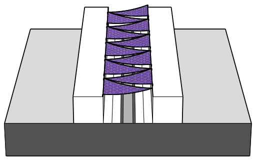
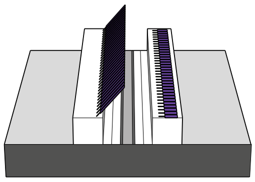
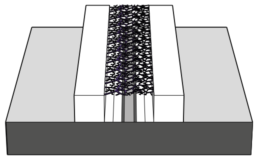


Figure 8.12: Artificial branches

Test bed 	 Treelane shading	 Moveable sails	 Moveable, reflective screens	 Artificial branches
Shortwave rad.				
Shading ^24 °C	+ +	+ +	+ +	+
No shading under 15 °C	0	+ +	+ +	0
Light intrusion	0	+	+ +	0
No glares	+ +	+ +	+	+ +
Safety / Common				
Wide paths	-	+ +	+ +	+ +
Visibility for/of cyclists	0	+ +	+ +	+
Technical feasibility	+ +	+	-	+ +
Costs	0	0	-	+ +
Maintenance	- -	+ +	+ +	-
Total Score	**4th**	**1st**	**2nd**	**3rd**

8.3 Southwest routes

Southwest streets have moderate problems concerning shortwave radiation. During summer these streets are shaded/radiated half. So it is not as strongly radiated or heated by the sun as the west to east oriented streets. The largest problem is formed during morning or evening sun, when the sun is low and shines from the east or west location. The higher houses provide large shadows during these situations. The sun reaches higher during the day and creates shorter shadows in the middle of the day. In winter these situations are worse because the sun angle is lower, thus longer shadows are created. The challenge is to use shortwave radiation in the winter as much as possible, where the shortwave radiation could be minimized during summer situations. Also morning and evening situations should be radiated more during the winter, to provide a thermally comfortable cycling environment.

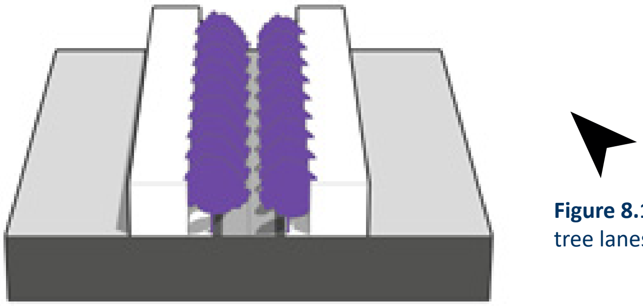


Figure 8.13: Densified tree lanes

The first solution (figure 8.13) shows an improved current situation, where the current tree lanes are densified with more trees to close the large gaps. This solution provides better shading than the current situation but also requires more space then normally. Although this solution does not cost a lot more to implement, other solutions score higher.

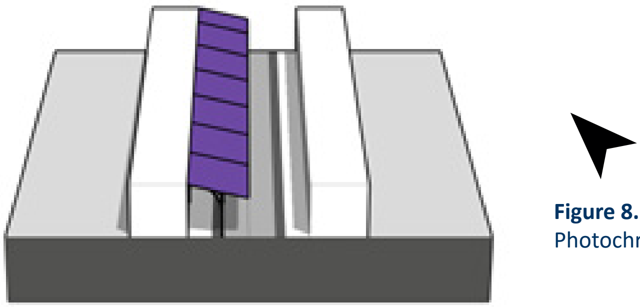


Figure 8.14: Photochromic glass

In figure 8.14 photochromic glass is used to protect people from too much sun during warmer days and to have an open sky during colder days. This solution provides intermediate protection during warmer days and colder days, but does not reflect extra incoming sunlight during winter conditions. It is simple to implement, but the costs will be quite high due to the photochromic glass which is needed to construct this solution.

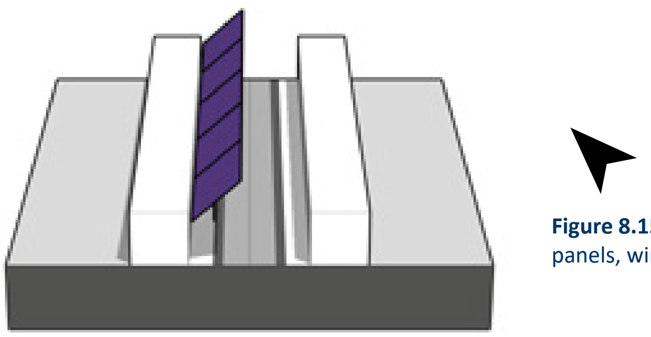


Figure 8.15: Moveable panels, winter

The third solution (figure 8.15) displays the same idea of screens, made from a different material and the awnings are moveable in a desired angle. This solution is even more expensive than the second solution, but is more effective for protecting cyclists during warmer days and allowing sun during colder days. It reflects the low incoming sun over the rooftops to the street to use the available radiation in winter days, when this radiation is needed. This solution also does not need much space on the street itself and does not interact with the existing infrastructure.

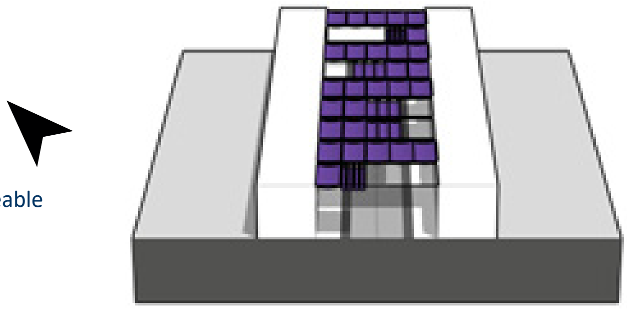
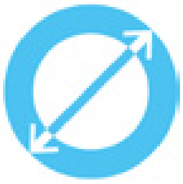
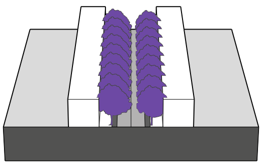
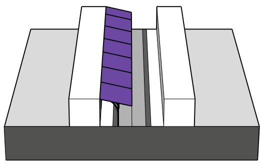
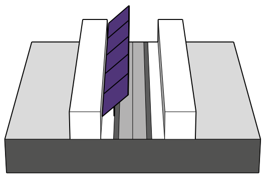
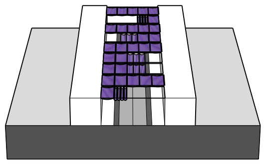


Figure 8.16: Moveable screens

The fourth solution uses moveable screens (figure 8.16) to protect cyclists during warmer days, but could be opened easily to allow the shortwave radiation when desired. The last mentioned solution scores highest because it covers almost all criteria with good ratings.

Test bed 	 Densified tree lane	 Photochromic glass	 Moveable panels	 Moveable screens
Shortwave rad.				
Shading ^24 °C	+ +	+	+	+ +
No shading under 15 °C	0	+ +	+ +	+ +
Light intrusion	0	+	+ +	0
No glares	+ +	0	+	+ +
Safety / Common				
Wide paths	-	+	+ +	+ +
Visibility for/of cyclists	+	+ +	+ +	+ +
Technical feasibility	+ +	+	-	+
Costs	0	0	-	+
Maintenance	- -	0	+ +	+
Total Score	**4th**	**3rd**	**2nd**	**1st**

8.4 Waterfront routes

Shortwave radiation is foremost a problem during summer days for waterfront routes. There are not many buildings or trees which shade the cyclists during the day. Although this forms a problem during summer days, the shortwave radiation is beneficial during winter days. The cyclists are radiated for a large part during the day in winter situations. The most important is to protect cyclists during warmer days of summer.

The first solution displays a double row of trees (figure 8.17). The trees and the large building on the other side of the paths cast shadow for more than half of the day on the cycle paths. Cyclists are only not shaded during the middle of the day of summer days. These trees provide enough shade during hot days. Unfortunately, trees also provide shade during colder days.

A second solution also uses green to shade cyclists. Figure 8.18 shows an overgrown pergola. This pergola is able to shade cyclists during the whole day in combination with the building. Pergolas provide better shading and less maintenance than a single or double tree lane, but are also covered during the mornings or colder days of a summer. The pergola is not covered from fall until spring, thus allows sunlight during colder days of the year.

The third solution shows a solution where moveable screens are used to influence shortwave radiation (figure 8.19). When temperatures rise higher than 24 °C, these screens could be used for shading and could be moved where shading is preferred. If for example functions such as a café require space in the sun, this café is able to open up the screens. This solution provides flexibility in light intrusion and a better microclimate for cyclists for both warm and cold conditions.

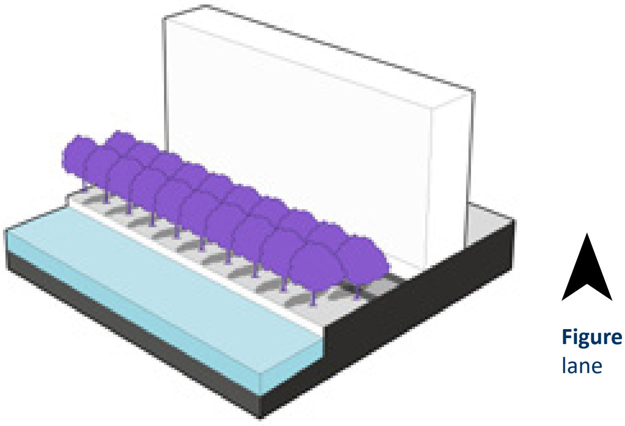


Figure 8.17: Double tree lane

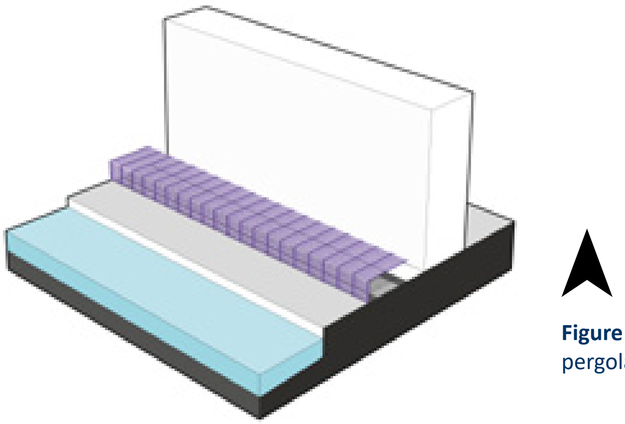


Figure 8.18: Green pergola

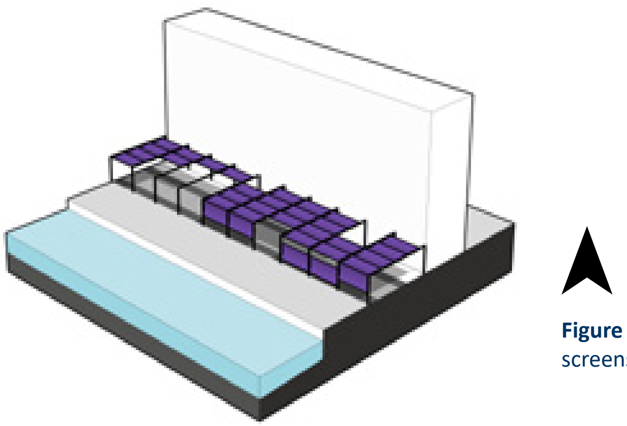
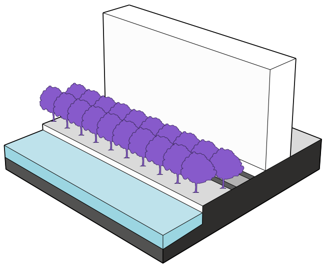
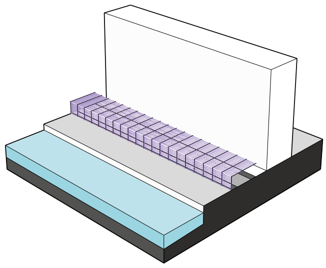
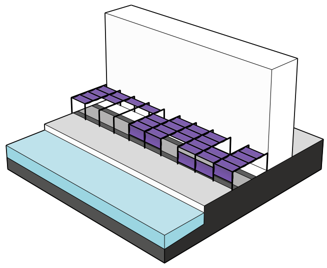


Figure 7.19: Adjustable screens

Test bed 	 Double tree lane	 Green pergola	 Adjustable screens
Shortwave rad.			
Shading ^24 °C	+	+ +	+ +
No shading under 15 °C	0	0	+ +
Light intrusion	0	0	+ +
No glares	+ +	+ +	+ +
Safety / Common			
Wide paths	+ +	+ +	+ +
Visibility for/of cyclists	+ +	+ +	+ +
Technical feasibility	+ +	+	+
Costs	+	+ +	+
Maintenance	- -	0	+
Total Score	**3rd**	**2nd**	**1st**

8.5 Open routes

Open routes cope with the same problem as waterfront routes, which is too much shortwave radiation during summer situations. Bridges or open routes are not shaded at all. Open routes or bridges do not provide much space to design interventions and these interventions do not have to be too heavy (because the bridge is not able to carry too much weight).

The first solution shows green pergolas covering the cyclists from shortwave radiation (figure 8.20). This intervention covers cyclists very well during warmer days but is not completely open during colder days. The light intrusion is not optimal, because the cycle path is shaded for a large part of the year. This also means the visibility of cyclists is less and cyclist are not fully able to see all other traffic on the other side of the green wall. To design with green also means that a certain degree of maintenance is needed.

The second solution shows a flexible intervention to deal with shortwave radiation (figure 8.21). Screens are covering the cyclists when desired, but could be folded during colder situations. The amount of incoming shortwave radiation can be regulated in this way and provides optimal shading and light intrusion. The lowest scoring criterion of the second solution is costs. All the other scores are good or very good.

The third solution (figure 8.22) is also a solution which can be implemented when less space is available, such as on the open type. Photochromic glass is used to shade cyclists during hot days, but it has the ability to be open during colder days. The shaded tone in the photochromic glass differs from transparent during colder days, to dark shaded during warmer days. Advantages of this glass are perfect shading and openness when desired and a good light intrusion on the path. The major disadvantages are possible glares of reflecting glass panels, malleability (heavy materials on the bridge) and the costs.

The highest scoring solution (figure 7.21) is the second solution. The intervention is simple, light-weight and adjustable to provide thermally comfortable conditions for cyclists during the year.

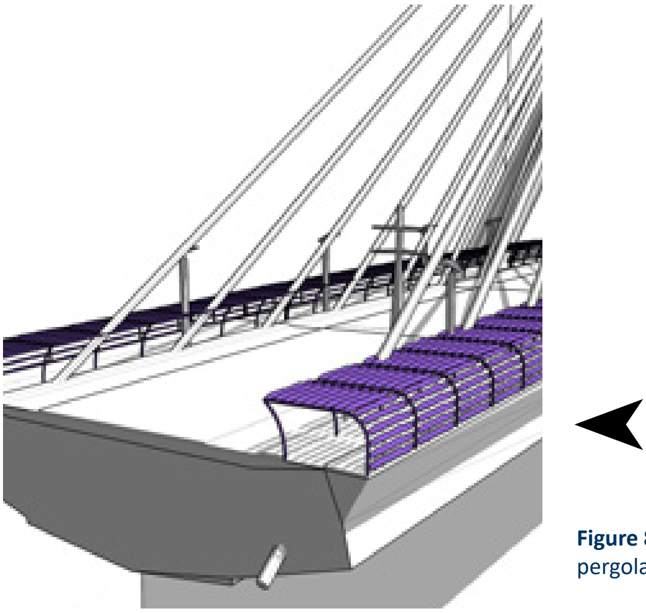


Figure 8.20: Green pergolas cover

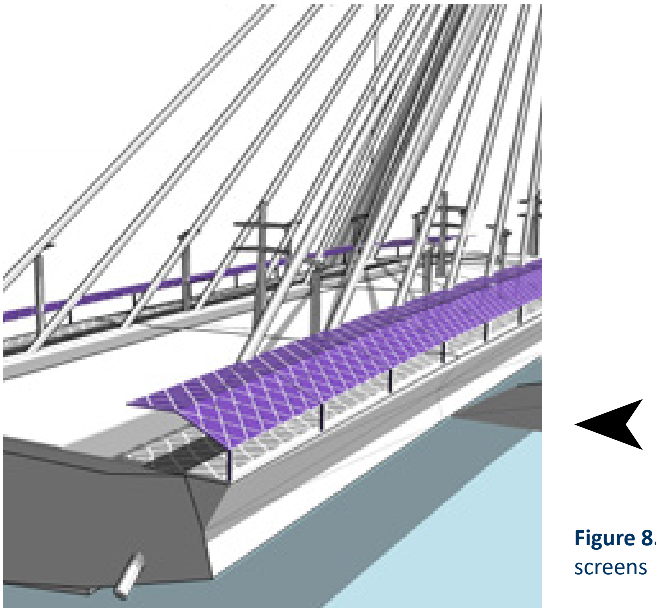


Figure 8.21: Adjustable screens

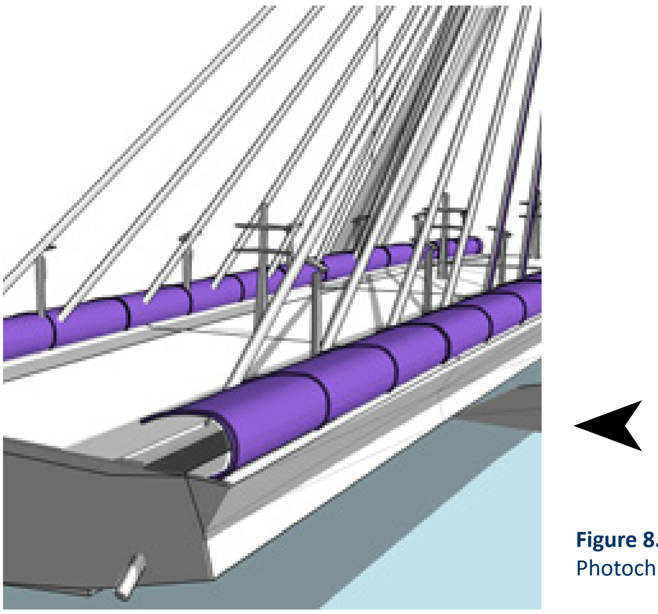
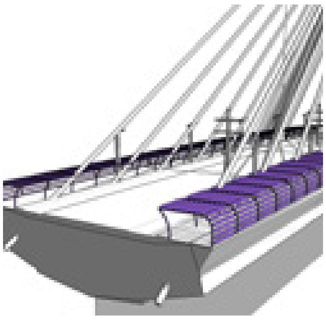
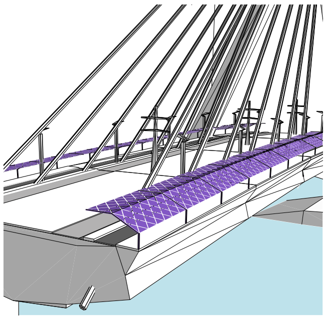
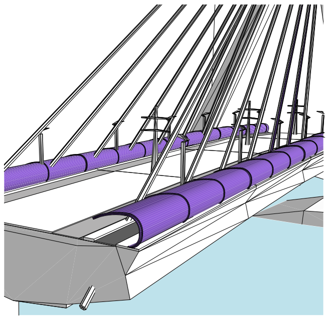


Figure 8.22: Photochromic glass

Test bed	 Green pergolas cover	 Adjustable screens	 Photochromic glass
Shortwave rad.			
Shading ^24 °C	+ +	+ +	+ +
No shading under 15 °C	0	+ +	+ +
Light intrusion	0	+	+ +
No glares	+ +	+ +	-
Safety / Common			
Wide paths	+ +	+ +	+ +
Visibility for/of cyclists	0	+ +	+ +
Technical feasibility	+	+	0
Costs	+	0	-
Maintenance	0	+	+
Total Score	**3rd**	**1st**	**2nd**

9. Solutions for precipitation

This chapter focusses on finding design solutions for precipitation (SQ8). Precipitation has many forms; rain, hail, snow and fog. Precipitation can be a problem when temperatures are below 15 °C. The impact of precipitation can cool down the body and worsen the thermal comfort of a cyclist.

9.1 Crossings

The first solution (figure 9.1) displays a simple awning. This awning protects cyclists from incoming precipitation, provides wide paths, good visibility and is simple to build. The glass panels and maintenance are the only lower scoring criteria.

Just a simple cover or a sort of umbrella is needed when cyclists need to be sheltered from precipitation. The second design (figure 9.2) is made out of umbrellas which also collect the precipitation. Lower and higher umbrellas are used to fully cover the paths. Although it protects cyclists very well from precipitation, the umbrellas form many obstacles in the line of sight of cyclists, and the amount of objects is expensive. Therefore, this design is not the highest scoring solution.

Flexible screens are also a possible solution (figure 9.3) to protect cyclists from precipitation. These screens can be fold out when it starts to rain, hail or snow. These screens only need a small support and a small intervention in the street design. It does not cost much, only maintenance is needed to ensure these screens work properly all year long.

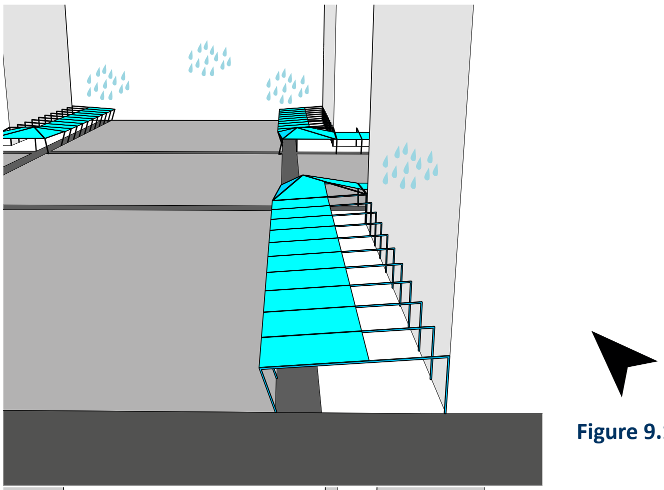


Figure 9.1: Glass awnings

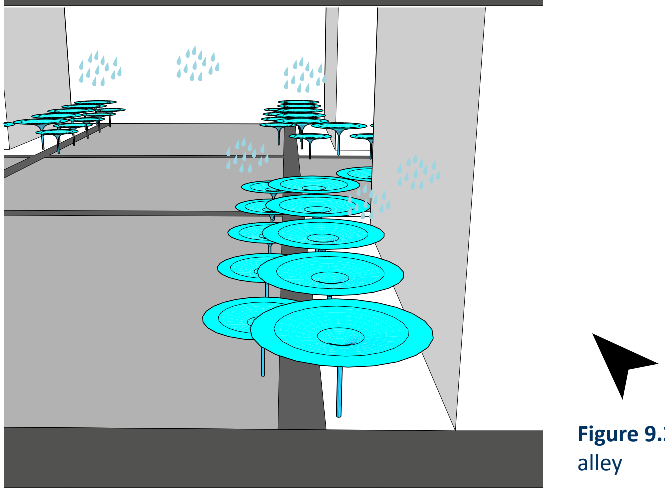


Figure 9.2: Umbrella alley

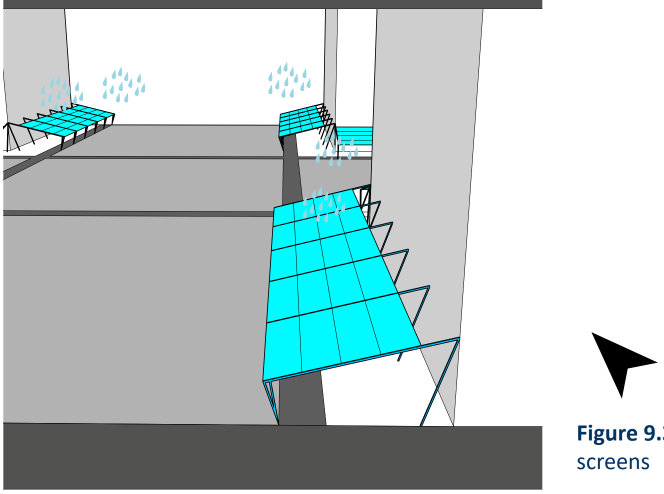
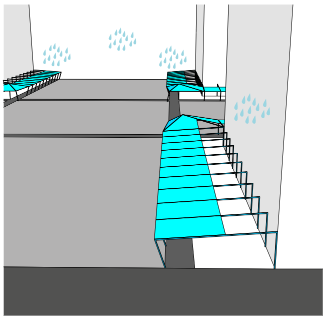
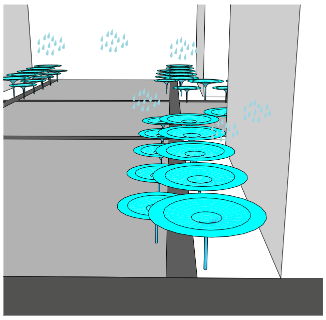
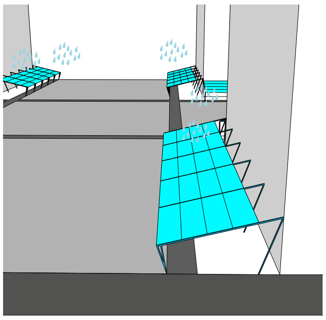


Figure 9.3: Flexible screens

Test bed	 Glass awnings	 Umbrella alley	 Flexible screens
Precipitation			
Cover direct impact	+	+ +	+ +
Safety / Common			
Wide paths	+ +	+ +	+ +
Visibility for/of cyclists	+ +	+	+ +
Technical feasibility	+ +	+	+
Costs	0	0	+ +
Maintenance	+	+	0
Total Score	**2nd**	**3rd**	**1st**

9.2 West - east routes

Crossings are too large to completely cover from precipitation. West to east oriented routes are smaller and could be covered completely from incoming precipitation. The first solution (figure 9.4) shows a foldable roof to protect cyclists. The roof is completely overarching the street and protects cyclists very well from incoming precipitation. Although this solution does not interfere with the street level, it is an expensive solution which needs a lot of effort to build and which needs a little effort to maintain. Another problem would be daylight intrusion for surrounding buildings. Therefore, this solution is not scoring as high as the other solutions.

A simpler, less costing idea is needed to find a useful solution for this spatial type. The second solution (figure 9.5) shows a minimal way to protect cyclists from incoming precipitation. Tilted awnings are catching the incoming precipitation, but do not fully cover the street. These screens do not need maintenance and provide a good sight for cyclists by using glass screens as awnings. Because this solution needs to be supported on street level, it decreases the path width slightly.

A third solution (figure 9.6) is designed to fully ensure wide paths and a good visibility for cyclists. A hanging roof is used to cover cyclists from incoming precipitation, without interfering with the street level. A simple hanging structure can be constructed and needs minimal maintenance in order to work properly.

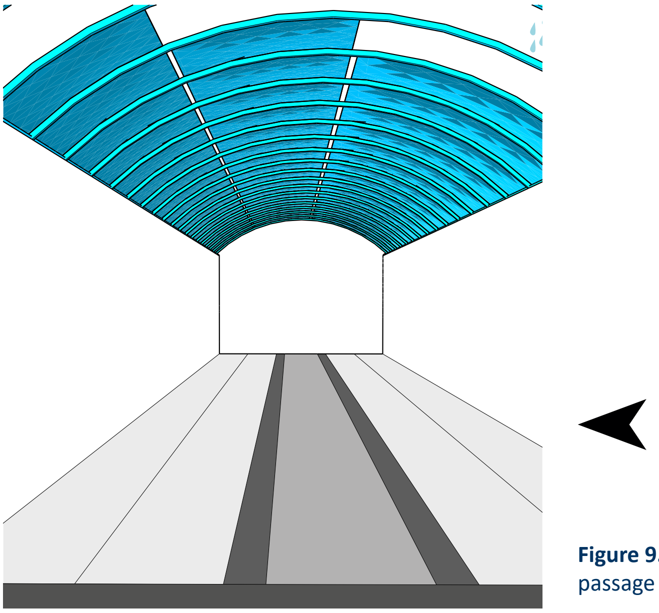


Figure 9.4: Flexible passage

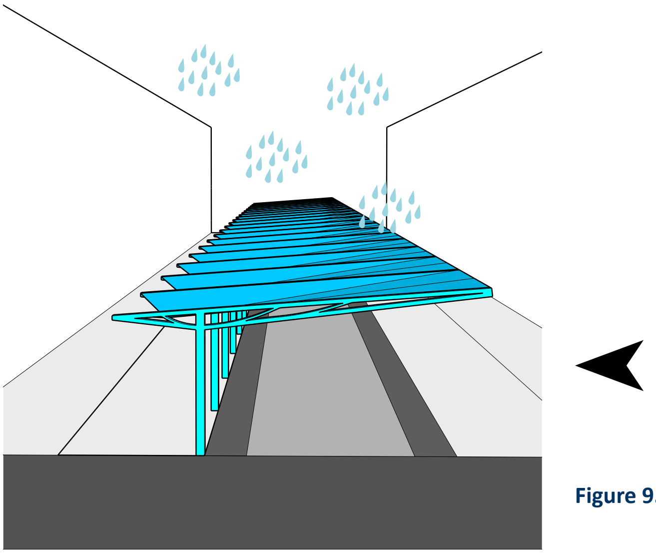


Figure 9.5: Canopies

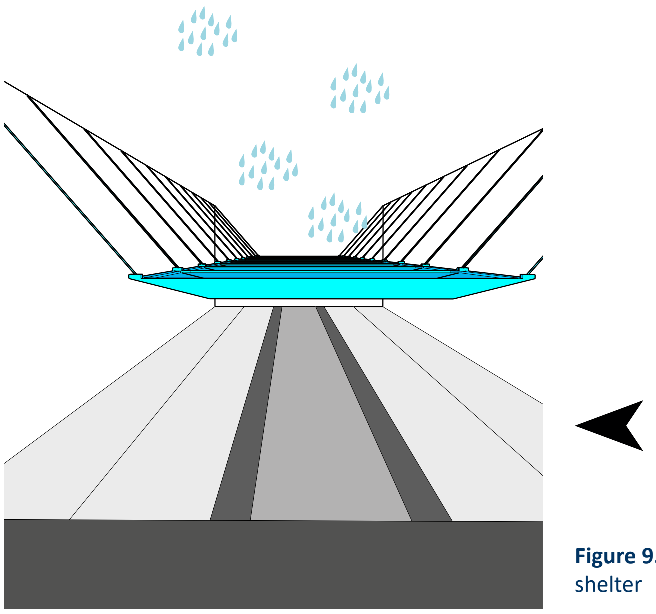
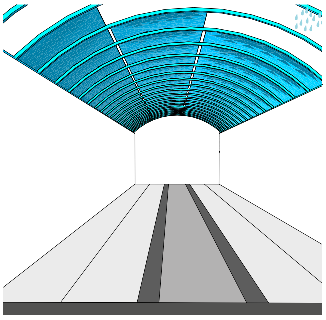
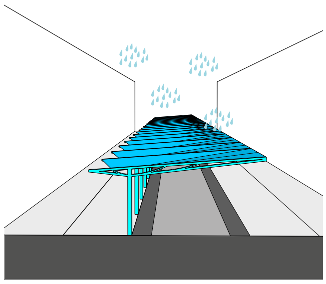
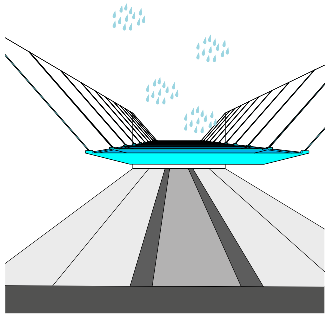


Figure 9.6: Hanging shelter

Test bed 	 Flexible passage	 Canopies	 Hanging shelter
Precipitation			
Cover direct impact	+ +	+	+
Safety / Common			
Wide paths	+ +	+	+ +
Visibility for/of cyclists	+ +	+ +	+ +
Technical feasibility	-	+	0
Costs	-	0	-
Maintenance	+	+ +	+ +
Total Score	**3rd**	**1st**	**2nd**

9.3 Southwest routes

Southwest routes can also be roofed in order to shelter cyclists from incoming precipitation. A fixed roof is designed in the first solution (figure 9.7) to cover cyclists. This, combined with inlaid glass roofs, ultimately protects cyclists from incoming precipitation and ensures wide paths. The costs of this solution are a downside. Because the roof does not have moving or growing elements, it needs minimal maintenance.

A second solution (figure 9.8) uses a more flexible solution. The overhanging roof can be opened when there is no incoming precipitation. Although it perfectly covers cyclists from direct impact of precipitation, it is a very expensive solution, which is not very technically feasible.

The previous two solutions were expensive, so a cheaper option is preferred. The third solution (figure 9.9) is smaller in size and therefore cheaper (less materials and construction hours are needed). Small moveable screens can be used to cover cyclists. These screens move above the cycle path when it starts to rain. This solution does not protect cyclists as good against precipitation as the other two solutions and needs a bit space on street level. This reduces the path widths a bit and the moveable screens also need maintenance a few times per year, to ensure they work properly.

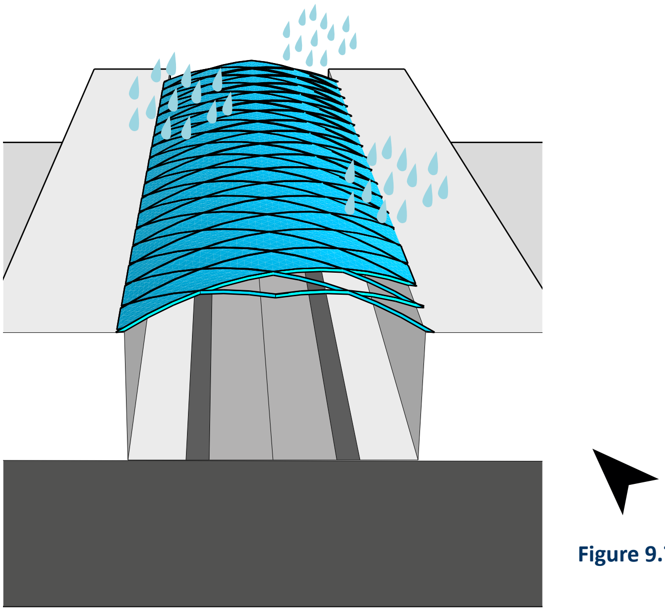


Figure 9.7: Fixed roof

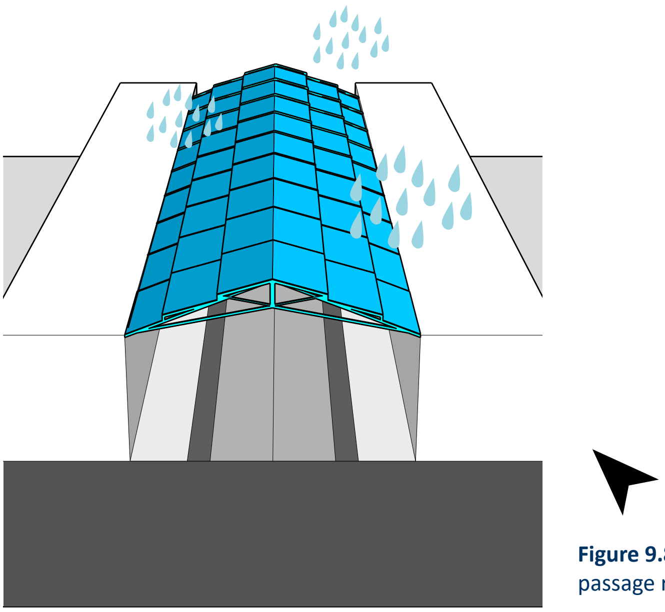


Figure 9.8: Flexible passage roof

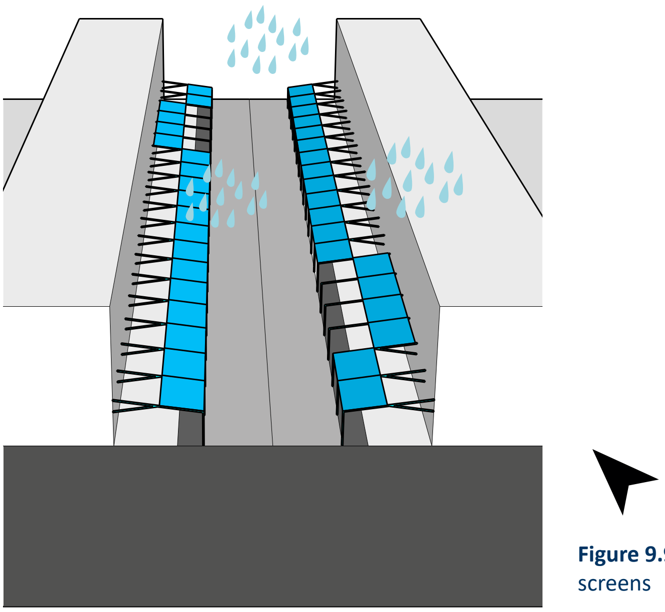
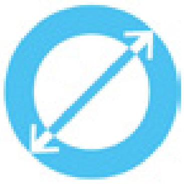
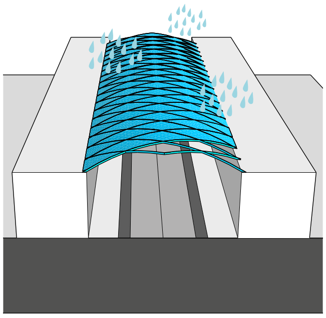
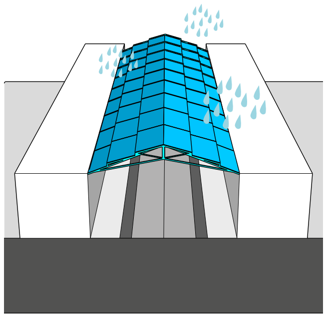
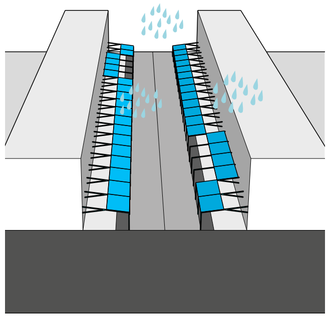


Figure 9.9: Rain-sensitive screens

Test bed 	 Fixed roof	 Flexible passage roof	 Rain-sensitive screens
Precipitation			
Cover direct impact	+ +	+ +	+
Safety / Common			
Wide paths	+ +	+ +	+
Visibility for/of cyclists	+	+	+ +
Technical feasibility	-	-	0
Costs	-	- -	0
Maintenance	+ +	+ +	+
Total Score	**2nd**	**3rd**	**1st**

9.4 Waterfront routes

A static glass roof is designed in the first solution (figure 9.10) to cover cyclists from incoming precipitation. This roof protects cyclists very well from incoming precipitation. This roofing provides enough space to cycle underneath and a good visibility is achieved by using a glass roof. This intervention is a simple idea, but difficult in execution. It is a quite expensive solution, because of the size.

The umbrellas are used in the second solution (figure 9.11). This is a less expensive solution, but it is also less effective in protecting cyclists from precipitation. It is a solution which does not need maintenance. The umbrellas provide an open structure which allows a lot of natural light. This leads to a good visibility of and for cyclists.

The third solution (figure 9.12) uses flexible screens to protect cyclists from the direct impact of precipitation. These screens are less expensive than the other solutions and cover cyclist from incoming precipitation very well. Despite of these benefits, it has a small disadvantage; the visibility is a bit worse than for the other solutions because the closed structure. Thereby, this solution needs more maintenance and is less technical feasible, because of the flexible screens.

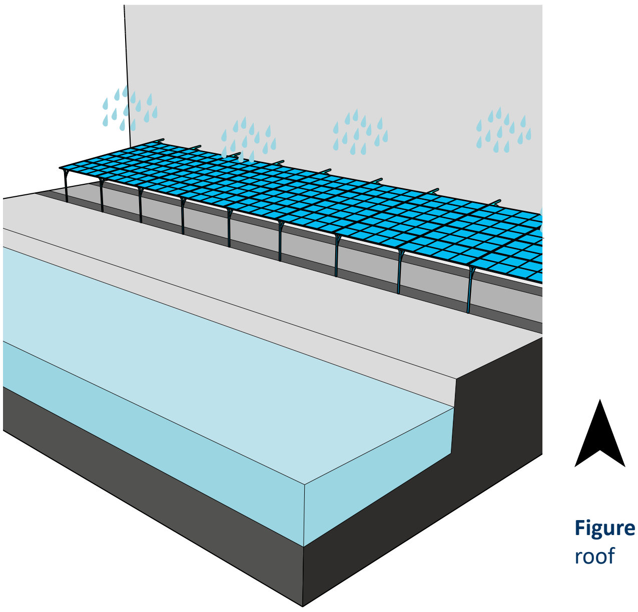


Figure 9.10: Static glass roof

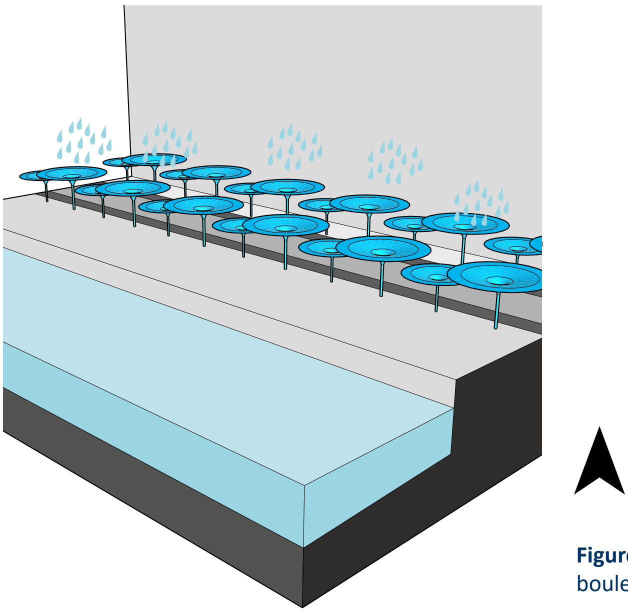


Figure 9.11: Umbrella boulevard

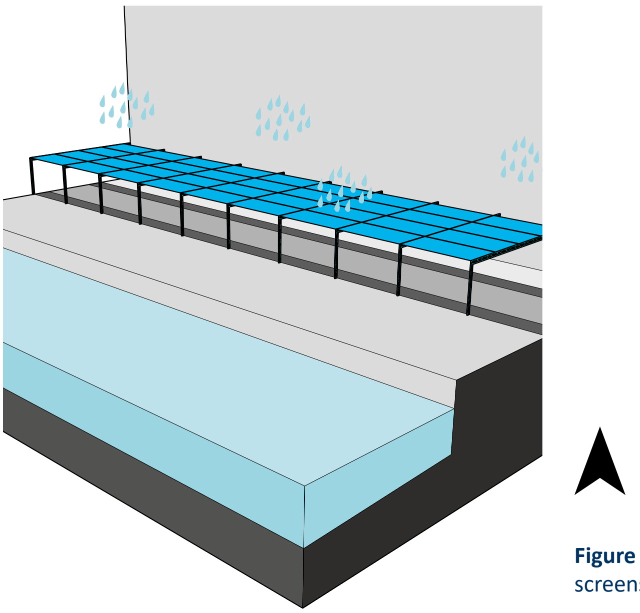
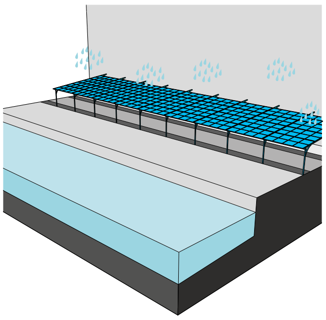
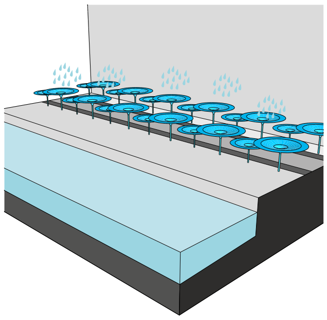
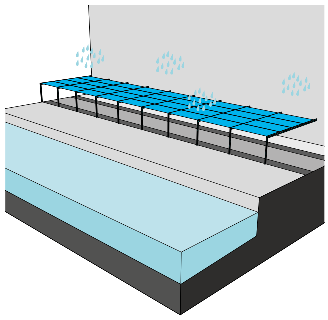


Figure 9.12: Flexible screens

Test bed 	 Static glass roof	 Umbrella boulevard	 Flexible screens
Precipitation			
Cover direct impact	+ +	+	+ +
Safety / Common			
Wide paths	+ +	+ +	+ +
Visibility for/of cyclists	+ +	+ +	+ +
Technical feasibility	+	+	0
Costs	-	-	+
Maintenance	+ +	+ +	+ +
Total Score	**2nd**	**3rd**	**1st**

9.5 Open routes

The first solution (figure 9.13) shows glass screens protecting cyclists from precipitation. This solution shelters cyclists very well from incoming precipitation. The glass ensures a good visibility for and of the cyclists but the heavy glass also burdens the bridge. The glass intervention is also quite expensive and not easy to build.

Flexible screens are used in the second solution (figure 9.14). This solution allows an open sky during situations of no precipitation, but can be closed to cover cyclists from precipitation when needed. The screens are of lightweight material and the construction is also of a very lightweight material such as aluminum. The shelter is open for the largest part of the year and ensures a good sight around the cyclists. The sight is slightly hindered during precipitation situations. The solution is not one of the cheapest solutions, because of the use of aluminum which is not very cheap. A bit of maintenance is needed to ensure the flexible screens work properly.

A pergola design is displayed in the third solution (figure 9.15). Climbers are planted along these pergolas on the side of the bridge deck. The leaves of the climbers protect cyclists from incoming precipitation, but not for a very long time. This solution is especially aimed at short rain showers. The leaves become heavy after a longer duration of rain. In the beginning rain will flow to the river, but after a while it falls right through the leaves of the climbers. Although it is not super effective against long showers, it provides space for wide paths and a good visibility for and of the cyclists. The pergola is simple to construct and not very expensive. Lightweight materials can be used to upgrade the technical feasibility but will cost more. Maintenance is needed to retain the plants on top of the pergolas.

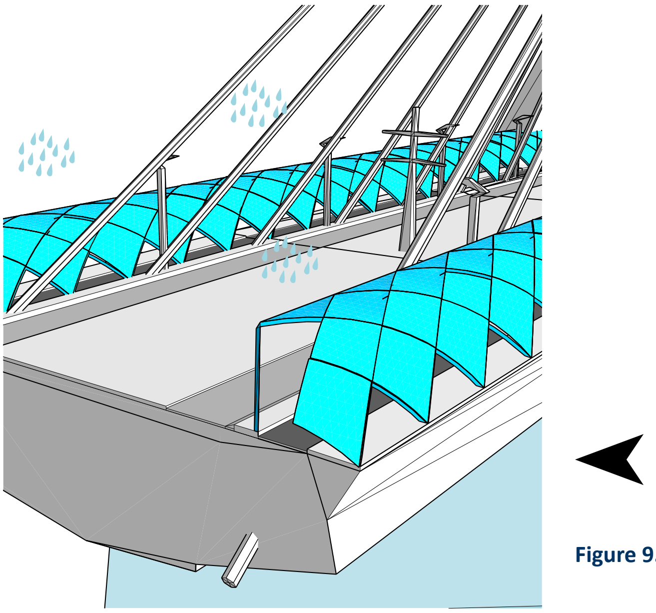


Figure 9.13: Glass shelter

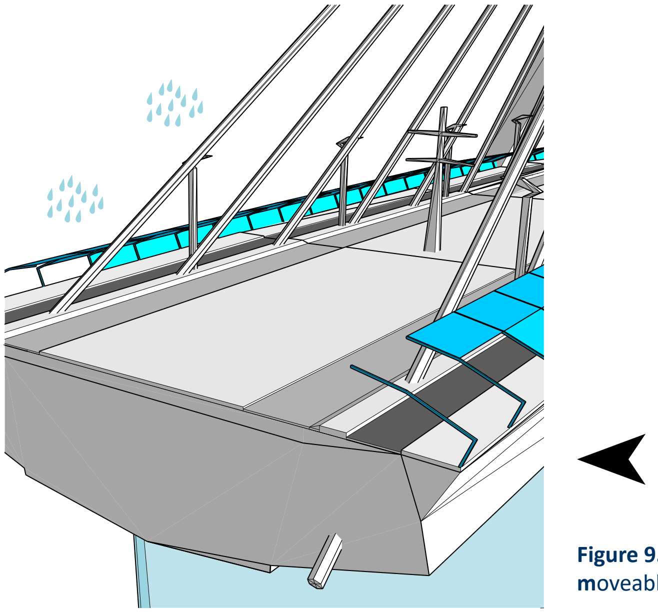


Figure 9.14: Lightweight moveable screens

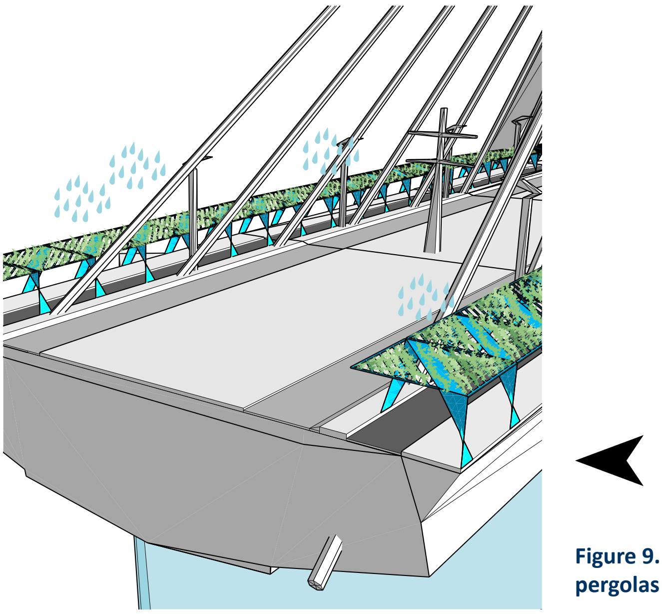
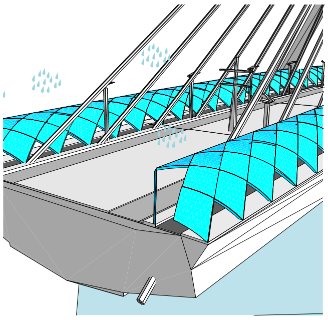
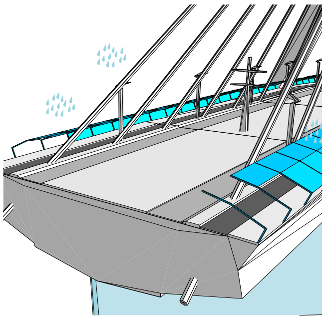
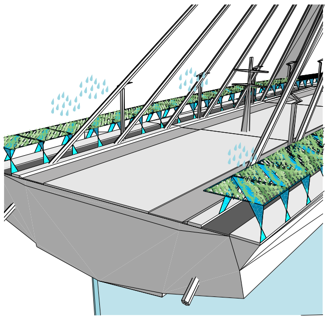


Figure 9.15:Green pergolas

Test bed	 Glass shelter	 Lightweight moveable screens	 Green pergolas
Precipitation			
Cover direct impact	+ +	+ +	0
Safety / Common			
Wide paths	+	+ +	+ +
Visibility for/of cyclists	+ +	+	+ +
Technical feasibility	-	+ +	+
Costs	-	-	+
Maintenance	+ +	+	0
Total Score	**3rd**	**1st**	**2nd**

Conclusion RTD Part 1

This overview of best the scoring solutions summarizes the first design iteration. The problematic spatial types are set on the X-axis and the thermal perception problems are set on the Y-axis. The first row of every problem shows the highest scoring solutions, the second row shows the second highest scoring solutions per specific thermal perception problem and per test bed. This matrix also answers the specific questions 5, 6 and 7. The outcomes of this part are used in RTD part 2, which provides integrated and implemented solutions.

[SQ5] Design principles to improve thermal perception of a cyclist coping with wind.

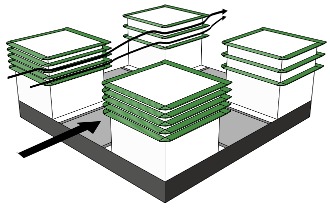
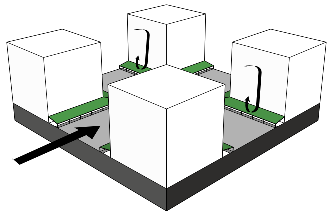
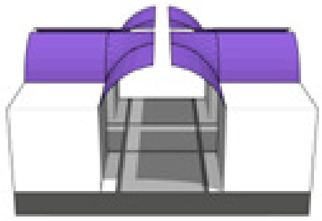
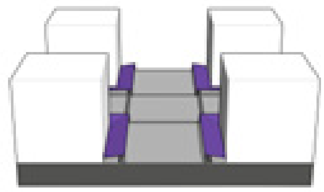
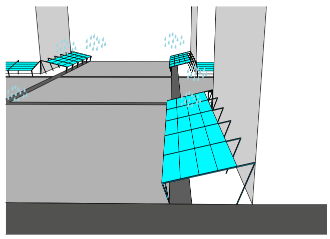
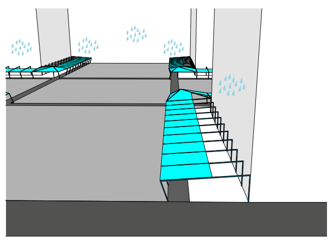
1. Flexible awnings
2. Downwash preventing awnings
3. Adjustable awnings
4. Narrow street profile at roof level
5. Tailwind cyclepath
6. Evergreen trees with openings
7. Tailwind advantage
8. Simple protection awnings
9. Cyclist propelling vents
10. Cyclist propelling screens

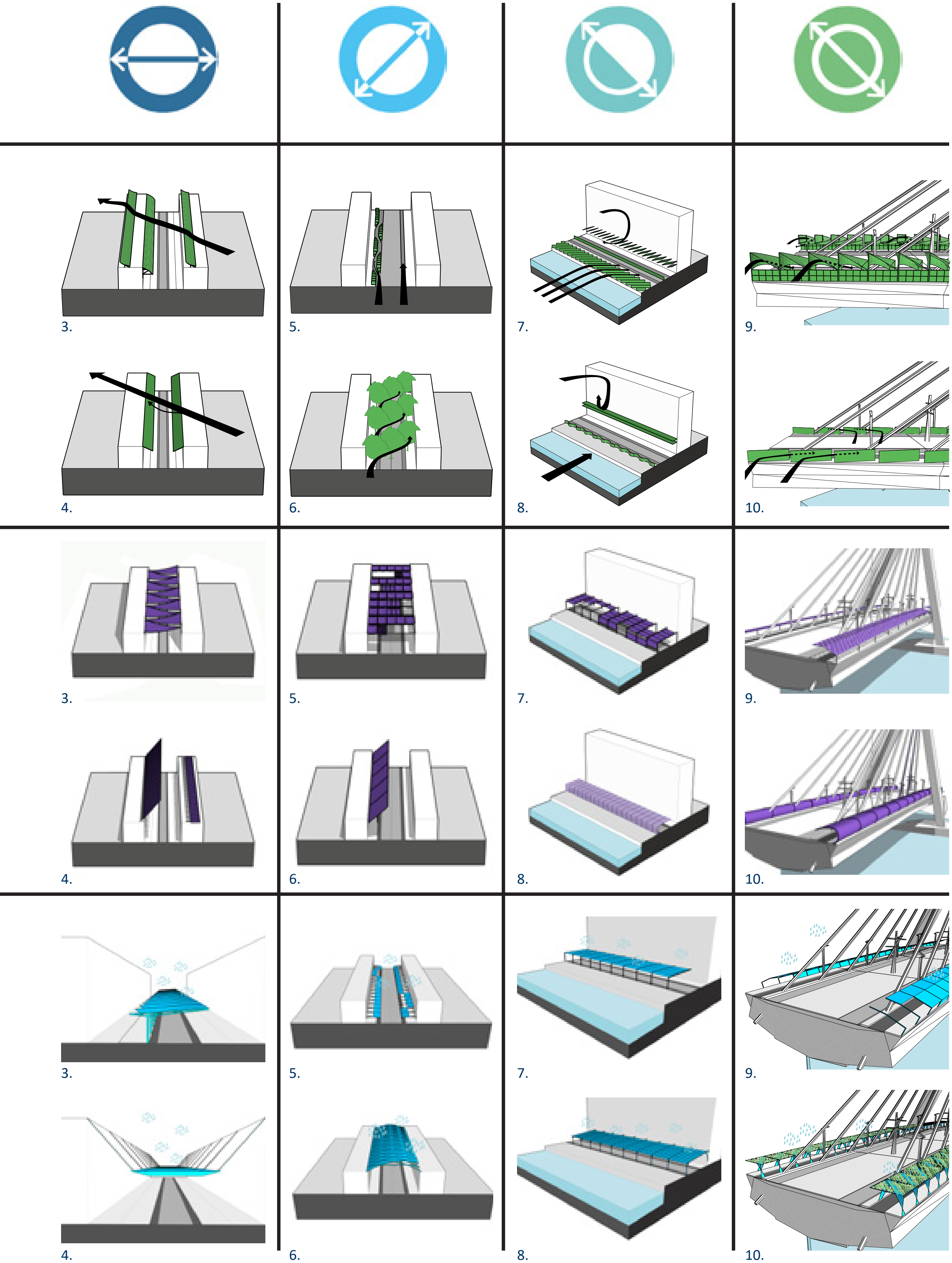
[SQ6] Design principles to improve thermal perception of a cyclist coping with short wave radiation.

1.Moveable awnings and reflectors
2. Simple photochromic glass intervention
3. Moveable sails
4. Moveable reflective screens
5. Moveable screens (SW routes)
6. Moveable panels
7. Adjustable screens (Waterfront routes)
8. Green pergolas
9. Adjustable screens (Open routes)
10. Photochromic glass

[SQ7] Design principles to improve thermal perception of a cyclist coping with precipitation.

1. Flexible screens
2. Glass awnings
3. Canopies
4. Hanging shelter
5. Rain-sensitive screens
6. Fixed roof
7. Flexible screens
8. Static glass roof
9. Lightweight moveable screens
10. Green pergolas

Problem \ Test bed		
WIND	1st	 1.
	2nd	 2.
SHORTWAVE	1st	 1.
	2nd	 2.
PRECIPITATION	1st	 1.
	2nd	 2.


3.
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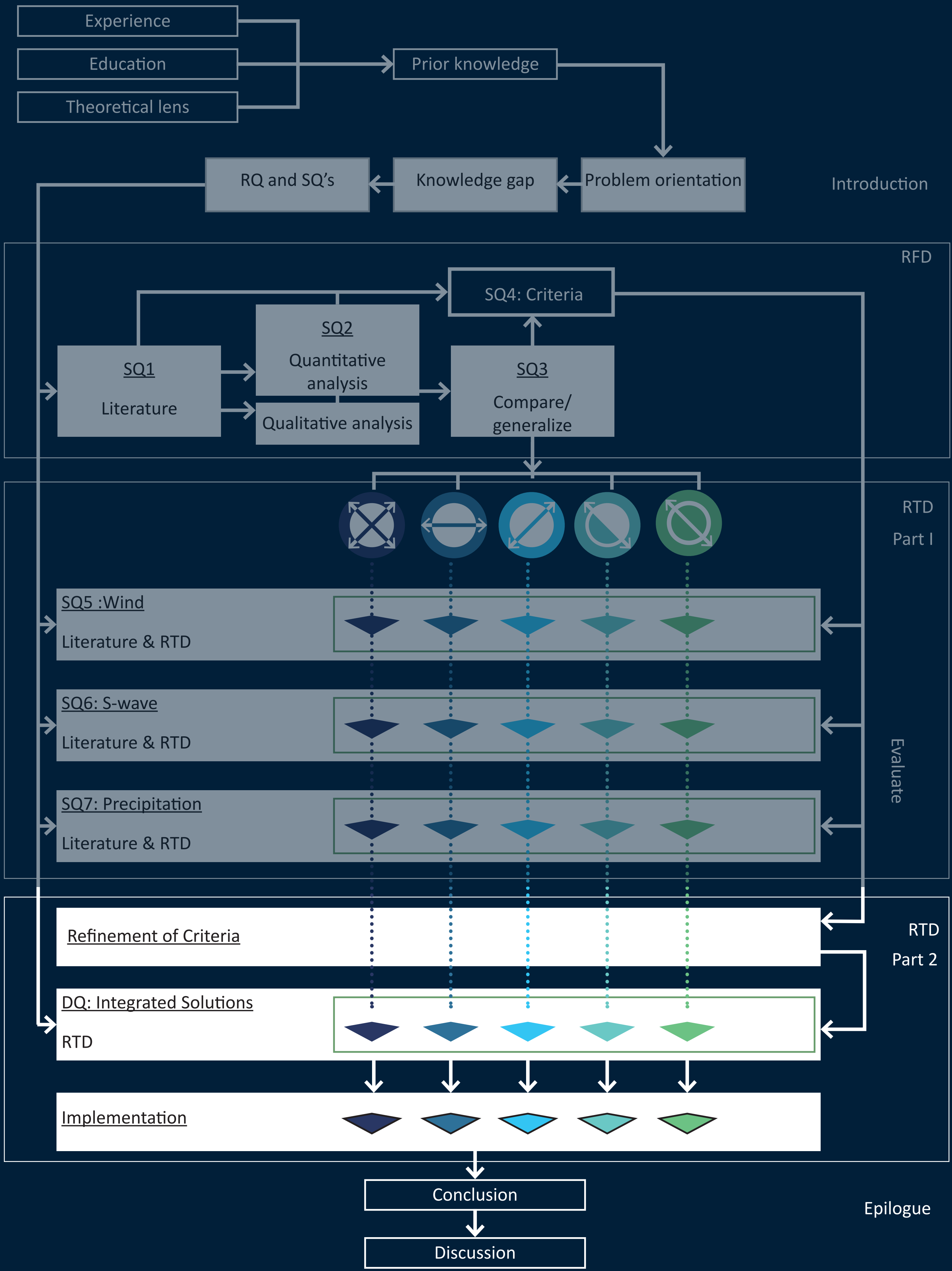
10.

Research Through Design Part 2

RTD part 1 synthesized separate solutions aiming to improve the thermal perception coping with wind, shortwave radiation and precipitation. The assessment matrix is revised in chapter 10. RTD part 2 combines the separate solutions in integrated solutions (chapter 11). The integrated phase delivers 5 highest rated solutions, which will be implemented in the existing places of Rotterdam (chapter 12). The last chapter provides an answer on which solutions improve the thermal perception of cyclists during uncomfortable weather situations (MRQ).


Experience
Education
Theoretical lens
Prior knowledge
RQ and SQ's
Knowledge gap
Problem orientation
Introduction
RFD
SQ4: Criteria
SQ2
Quantitative analysis
SQ1
Literature
Qualitative analysis
SQ3
Compare/ generalize
RTD
Part I
SQ5 :Wind
Literature & RTD
SQ6: S-wave
Literature & RTD
SQ7: Precipitation
Literature & RTD
Evaluate
Refinement of Criteria
RTD
Part 2
DQ: Integrated Solutions
RTD
Implementation
Conclusion
Discussion
Epilogue

10. Refinement of the assessment criteria

The previous part synthesized solutions for 3 types of problems; wind, shortwave radiation and precipitation. A set of criteria is used (see chapter 6) to test these solutions. These parameters or criteria were derived from the research for design part (chapters 3, 4 and 5), in order to tackle the ill-defined problems occurring on these problem routes.
Although these criteria were useful for testing the solutions, a level of refinement is required in order to come up with realistic and satisfying solutions (Lenzholzer & Brown, 2016; Rittel & Webber, 1973). Refining and framing a design or criteria is common in design or design research (Cross, 2006). The purpose of this research is to aim for a healthier life of people by stimulating them to use the bike in everyday situations. The final designs should promote cycling and a healthier lifestyle, without neglecting other elements of a healthy life. The testing criteria are sharpened in this chapter in order to facilitate human health and to create realistic solutions.

The criteria for wind and precipitation do not neglect human health, but encourage a healthier lifestyle and make the probability of cycling higher if the design solutions score high (Böcker, 2014; Eliasson, Knez, Westerberg, Thorsson, & Lindberg, 2007; Helbich, Böcker, & Dijst, 2014). The criteria 'shading above 24 °C', 'no shading under 15 °C' and 'No glares' of shortwave radiation criteria remain the same, because they also positively contribute to a higher cycling probability. But the criterion 'light intrusion' (to adjacent buildings and on street level) should be taken very serious. Human health will be affected if design solutions darken the street or inside the buildings (see chapter 6.2). The weight of the 'no glares' criterion stays the same. Glares should be prevented as much as possible to provide a safe cycling environment.

The safety and general criteria need to be changed. 'Wide paths', 'visibility for/of cyclists and maintenance' remain unchanged; these criteria are often subject to certain measurements. However 'technical feasibility' and 'costs' must be reviewed. The RFD part defined 'technical feasibility' as how 'realizable' or how much research or knowledge is needed in order to construct a certain solution. For example photochromic solutions need to be developed and are not produced in large numbers yet, which means a lower score on 'technical feasibility'. This term needs to be redefined as 'how achievable/feasible is this solution in the existing situation?' In other words: can the solution be executed immediately or does the environment (e.g. buildings, streets and trees) need to be drastically adjusted before implementation? Results of this thesis must be applicable and easy to implement for landscape architects or urban designers. This requires that the scores of the criteria 'technical feasibility' and 'costs' embody a double weight.

Summarizing, this means that the criteria; 'light intrusion, technical feasibility and costs' receive a double value in RTD part 2. The criteria marked in blue score are able to have a higher score than all other criteria. All criteria remain in the same rating-scale (- -, -, 0, + and ++), but the criteria marked in blue are multiplied by 2.

+ + = Very good
+ = Good
0 = Neutral
- = Bad
- - = Very Bad

Test bed	Solution 1	Solution 2	Solution 3
Wind			
Wind protection/diversion			
Wind admission (warm con.)			
Tailwind			
Less resistance			
Shortwave radiation			
Shading ^24 °C			
No shading under 15 °C			
Light intrusion *			
No glares			
Precipitation			
Cover direct impact			
Safety / General			
Wide paths			
Visibility for/of cyclists			
Technical feasibility *			
Costs *			
Maintenance			
Total Score	**(max 85)**	**(max 85)**	**(max 85)**

Figure 10.1: Refined assessment matrix

* = Double score

11. Integration

This chapter initiates a second phase of designing where the separate designs from wind, shortwave radiation and precipitation are integrated in cohesive design solutions. The integral assessment matrix of chapter 10 is used for rating the design solutions. One highest rated design per test bed is the end result of this chapter and will be elaborated/implemented in the next chapter.

11.1 Crossings

The first solution (figure 11.1 for summer and precipitation and 11.2 for winter or cold situation without precipitation) shows the fusion of the selected designs of RTD part 1 of crossings. The large canopy of shortwave is combined with the smart awnings for wind. The flexible screens of the precipitation design are also used to ensure maximal flexibility for every weather type. This fusion ensures good ratings for wind, shortwave radiation and precipitation. Although it scores higher on these parts, the design does not score very high on light intrusion, technical feasibility and costs, which lowers its final score. The roof completely darkens the street when the roof is closed (e.g. during rainy days or very warm days). Also the technical feasibility and costs score low, because of the size (materials) to build this intervention.

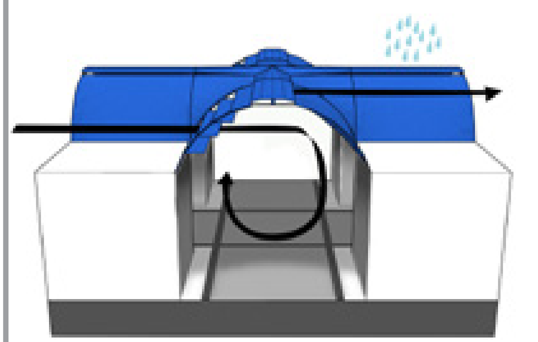


Figure 11.1: Large canopy, summer

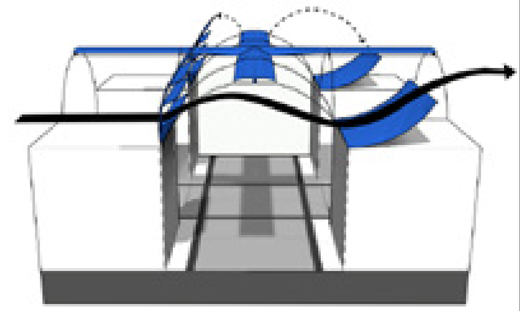


Figure 11.2: Large canopy, winter

A more realistic design is needed to aim for a higher score in 'light intrusion', 'technical feasibility' and 'costs'. This could mean that other criteria do not score as high as at the first solution, but are more realistic to implement. The second design solution (figure 11.3) blends the second best solutions of the first design phase. This fusion leads to awnings on street level. The second and third (figure 11.4) design solutions are two different possible fusions for these street level awnings. The second solution is a static solution, where a photochromic glass roof is used to solve the weather problems for cyclists. This solution is not the optimal answer for wind problems, but scores better on shortwave and precipitation criteria. The design also ensures a good light intrusion, because it uses the photochromic glass. This type of glass is also the reason why this design solution does not score very high on technical feasibility and costs criteria. It is possible to implement these glass panels, but the costs of this photochromic glass are quite high.

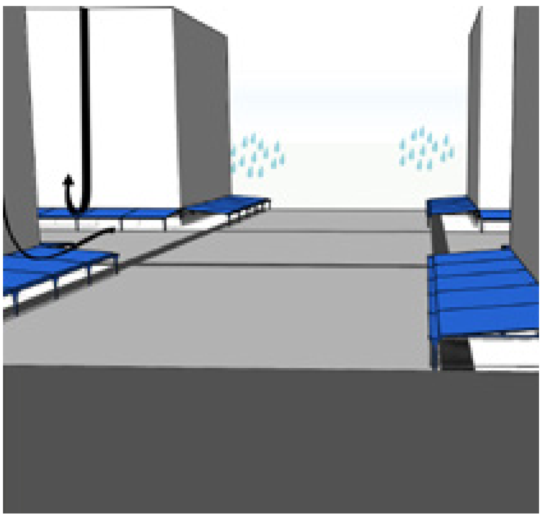


Figure 11.3: Small awnings of photochromic glass

The third solution (figure 11.4) uses a flexible

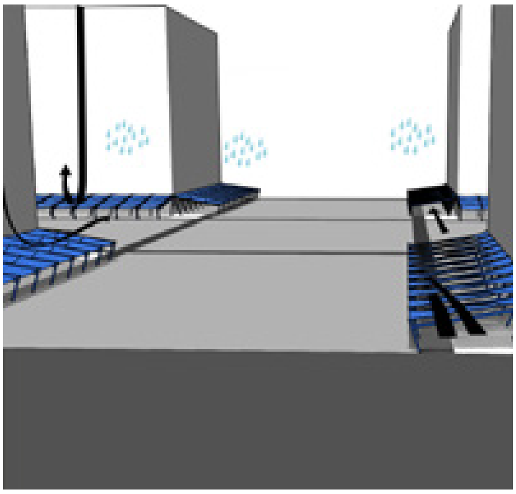
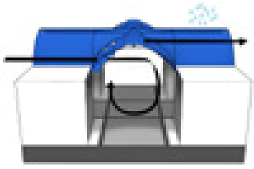
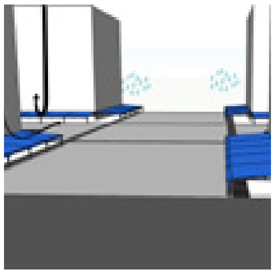
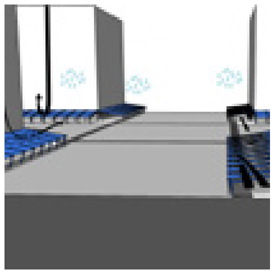


Figure 11.4: Flexible awnings

awning to cope with the weather problems. These screens can be used when it is too warm, windy or when it rains. These screens are folded when there is no/less wind, it is dry and/or too cold. These screens also provide more wind admission and even tailwinds for one direction (northeast direction). These screens also provide good shading in hot conditions, but could be closed during colder conditions (because of precipitation or hard winds). The precipitation cover is good but could be better. The screens are protecting the cyclists from precipitation, but can work less efficient in combination with hard winds. Although its flaws, the design scores very well as a realistic design in the safety and common section.

Test bed 	 Large canopy	 Photochromic glass awnings	 Flexible awnings
Wind			
Wind protection/diversion	+ +	0	0
Wind admission (warm con.)	+ +	0	+
Tailwind	- -	- -	0
Less resistance	+	0	+
Shortwave radiation			
Shading ^24 °C	+ +	+ +	+ +
No shading under 15 °C	+	+ +	-
Light intrusion *	-	+ +	0
No glares	+ +	-	+ +
Precipitation			
Cover direct impact	+ +	+	0
Safety / General			
Wide paths	+ +	+	+
Visibility for/of cyclists	0	+	0
Technical feasibility *	-	+	+
Costs *	-	0	+ +
Maintenance	+ +	+ +	+ +
Total Score	**55/85**	**63/85**	**65/85**

11.2 West - east routes

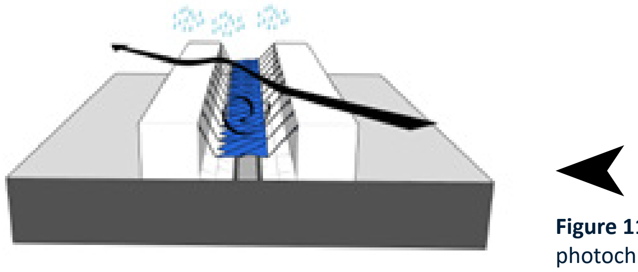


Figure 11.5: Hanging roof photochromic glass

The first design solution (figure 11.5) shows a hanging roof of photochromic glass. The roof ensures a good wind protection and less resistance. The design also scores very well in the shortwave section. The roof provides a good shelter from precipitation. The lower rated criteria are; wind admission during warmer conditions, tailwinds, glares and in the safety/general section; technical feasibility (surrounding buildings need to bear the weight of the intervention) and the costs of the design solution (photochromic glass).

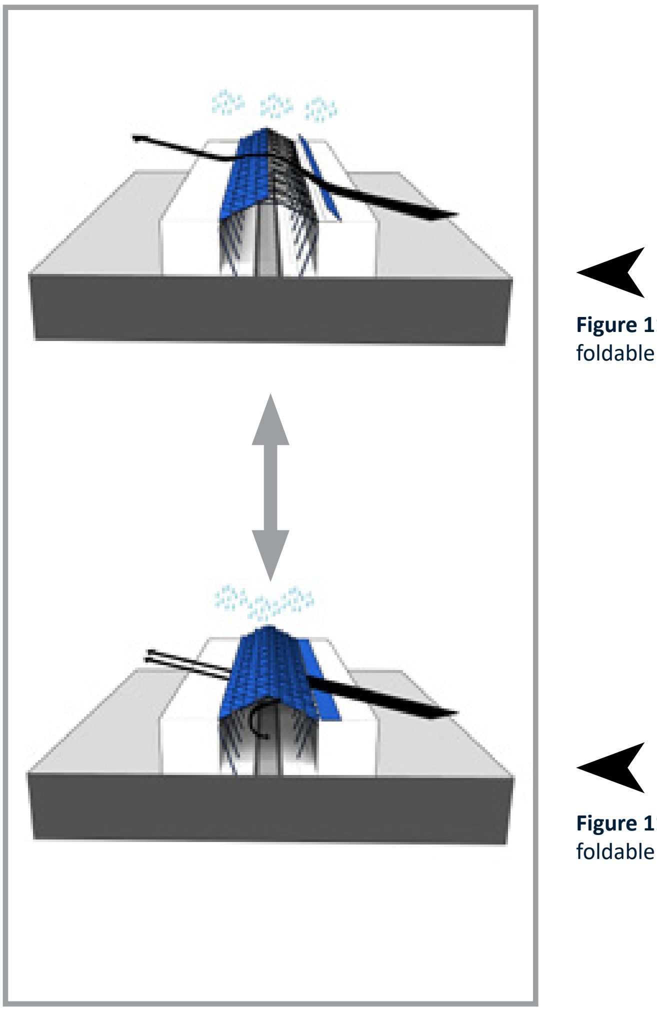


Figure 11.6: Complete foldable cover winter

Figure 11.7: Complete foldable cover summer

The second solution (figure 11.6 and 11.7) completely cover the street. This roof is made from foldable screens which are shaped in order to increase the advantage of the wind. The roof has openings in the wind facing direction when the roof is closed (figure 11.7) to allow cool winds on the street level. The roof is half-open when it is too cold and when there is no precipitation (figure 11.6). A small awning repels wind over the roof during this situation. The design solution scores very well on wind protection, wind allowance and less resistance, shading in warm conditions and precipitation protection. The roof does not score high for daylight intrusion, technical feasibility and costs.

The third design shows a flexible and smaller solution (figure 11.8). A simple solution with flexible screens is chosen, which could be adjusted to the problematic weather conditions. The solution has its foundations on the street and does not need constructions which bear the surrounding buildings. It has a medium score for the wind section, but a high score in the shortwave and precipitation section. The downsides of this design solution are; not always an open sky while colder conditions occur and light intrusion on street level could be better.

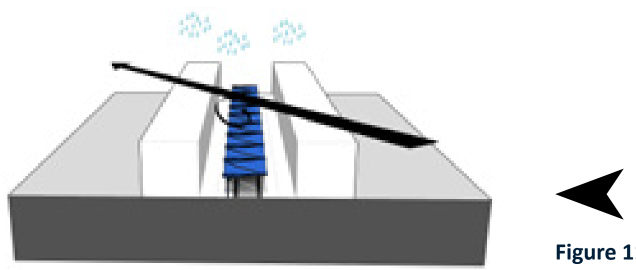


Figure 11.8: Small flexible awning with photochromic glass

An improved version of the roof with photochromic glass (first solution, figure 11.5) forms the fourth solution, where a photochromic glass roof is mounted on the street (figure 11.9). This solution has the same benefits as the hanging photochromic roof, but solves the problems of the first solution. The solution is more feasible, but still has the same costs as the first solution. Nevertheless, this last solution has a higher score than the first solution.

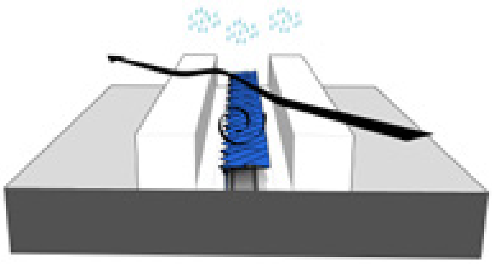
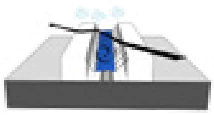
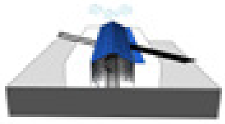
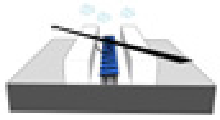
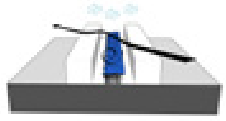


Figure 11.9: Ground mounted roof

Test bed 	 Hanging roof photochromic glass	 Complete foldable cover	 Small flexible awnings	 Ground mounted roof photochromic glass
Wind				
Wind protection/diversion	+ +	+	+	+ +
Wind admission (warm con.)	- -	+ +	-	- -
Tailwind	- -	- -	- -	- -
Less resistance	+ +	+ +	+ +	+ +
Shortwave radiation				
Shading ^24 °C	+ +	+ +	+ +	+ +
No shading under 15 °C	+ +	+	-	+ +
Light intrusion *	+ +	- -	0	+ +
No glares	-	+ +	+ +	-
Precipitation				
Cover direct impact	+	+ +	+	+
Safety / General				
Wide paths	+ +	+ +	+	+
Visibility for/of cyclists	+ +	0	+	+ +
Technical feasibility *	-	- -	+	+
Costs *	0	-	+ +	+
Maintenance	+ +	+ +	+ +	+ +
Total Score	**63/85**	**55/85**	**65/85**	**68/85**

11.3 Southwest routes

The first combined solution (figure 11.10) is a fusion of all best designs of the southwest facing routes. The solution is a combination of the tailwind cycle path, moveable screens and the rain sensitive screens. The screens on top of the cycle paths are made of photochromic glass and could provide cover from precipitation and too much sun. The screens on one side of the road are tilted to provide extra tailwinds. The other side of the road is sheltered with a winding path along hedges. These hedges and roofing protect cyclists from hard winds and minimize resistance. The screens provide shading in warmer conditions and are transparent in cooler conditions. Cyclists are covered well from incoming precipitation. Downsides of this design solution are the glares of the glass roofing and smaller paths.

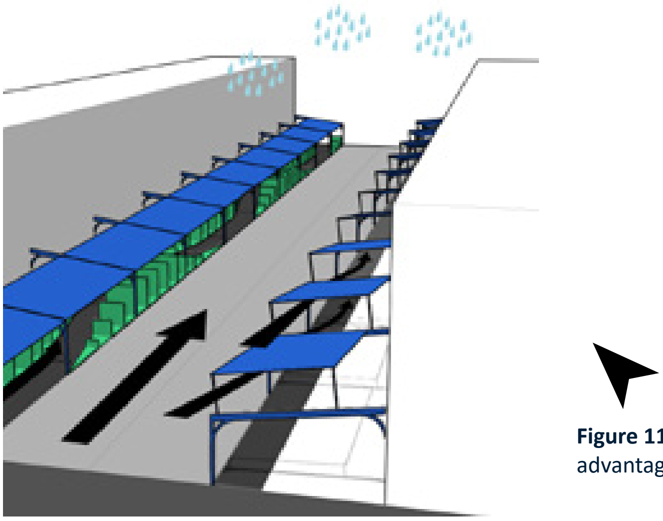


Figure 11.10: Tailwind advantage awnings

A combination of the fixed roof, the moving panels and more or less the evergreen trees with openings is made in the coming two solutions. Beforehand could be said that combining trees with a closed passage is not possible. Therefore two different combinations are made; one with the closed passage roof (figure 11.11) and one with the evergreen trees (11.12). The solution with the closed passage roof (figure 11.11) scores well on wind protection, less resistance, shading, open sky and glares and cover from precipitation. The big roof scores low on light intrusion, technical feasibility and costs. Therefore is this combination not recommended to use.

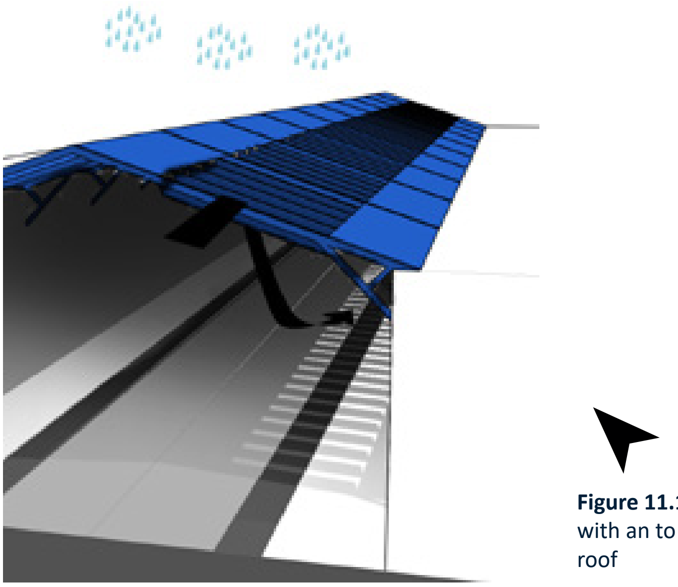


Figure 11.11: Passage with an to be opened roof

The third solution shows the fusion where the roof is eliminated (figure 11.12). Small awnings are designed with on top flexible screens. Evergreen trees are planted on the north side of the street to provide shade on the hottest side of the street and to slow down winds. The roof catches extra wind for tailwinds and protects people from precipitation and too much shortwave radiation. This fusion brings medium advantages for the wind section, but good scores for the shortwave radiation and precipitation sections. The design scores well at safety and common criteria but does not has the highest score. The first solution has more points than the other solutions.

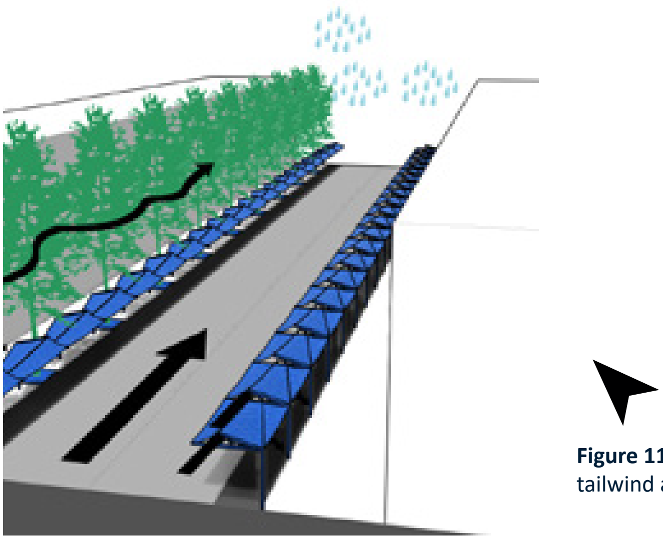
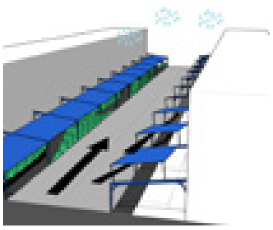
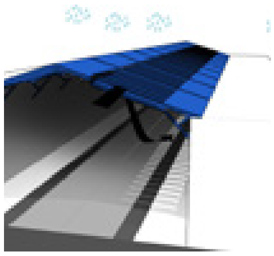
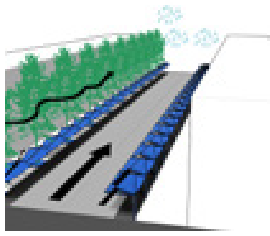


Figure 11.12: Flexible tailwind and cover

Test bed	 Tailwind advantage	 Passage with an to be opened roof	 Flexible tailwind and cover
Wind			
Wind protection/diversion	+ +	+ +	+
Wind admission (warm con.)	0	-	0
Tailwind	+	-	0
Less resistance	+ +	+	0
Shortwave radiation			
Shading ^24 °C	+	+ +	+
No shading under 15 °C	+ +	-	0
Light intrusion *	+	- -	0
No glares	-	+ +	+ +
Precipitation			
Cover direct impact	+	+ +	+
Safety / General			
Wide paths	0	+ +	+
Visibility for/of cyclists	+	0	0
Technical feasibility *	+	- -	+
Costs *	+	- -	+
Maintenance	+ +	+ +	0
Total Score	**68/85**	**49/85**	**61/85**

11.4 Waterfront routes

The first solution (figure 11.13) shows a blend of the tailwind advantage design and the static glass roof. The screens bend air in the desired direction to ensure tailwinds, good wind protection, wind admission during warmer conditions and less resistance. The photochromic glass roof also provides good shading in warm conditions, open sky during colder conditions and a good light intrusion. The roofing also ensures a good protection from precipitation. Downsides of this design are the glares of the glass, costs and it is not very technical feasible to have long strips of this intervention along the waterfronts.

The second solution uses flexible screens which can be closed (figure 11.14) during precipitation and too warm conditions, but can be open during colder conditions without precipitation (figure 11.15). Cyclists are still protected from downdrafts and winds from the side by the screens on the waterfront side and the screens mounted on the building facade. This overall wind protection provides good scores for wind (only tailwinds do score low), shortwave radiation and precipitation cover. The construction is relative lightweight, low in costs and easy to build.

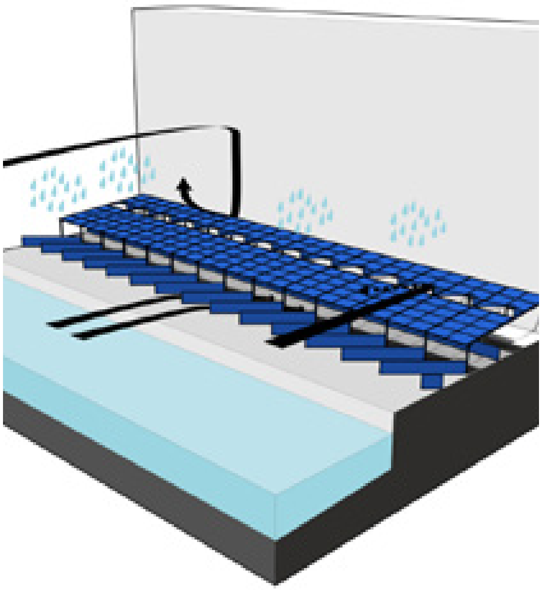


Figure 11.13: Tailwind static roof

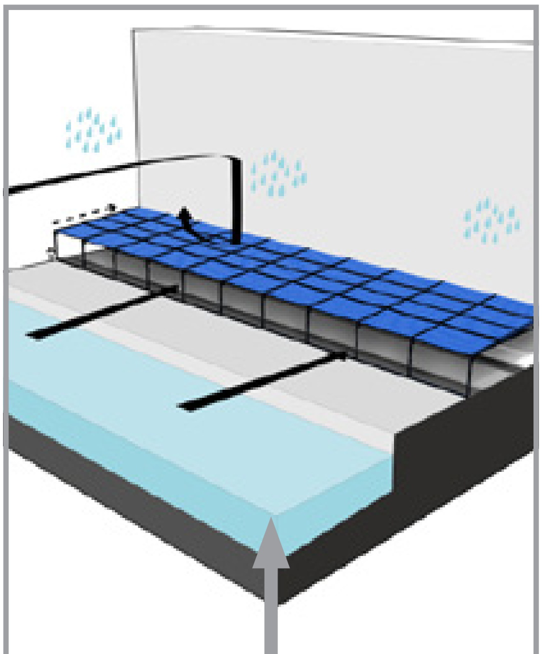


Figure 11.14: Flexible street cover summer

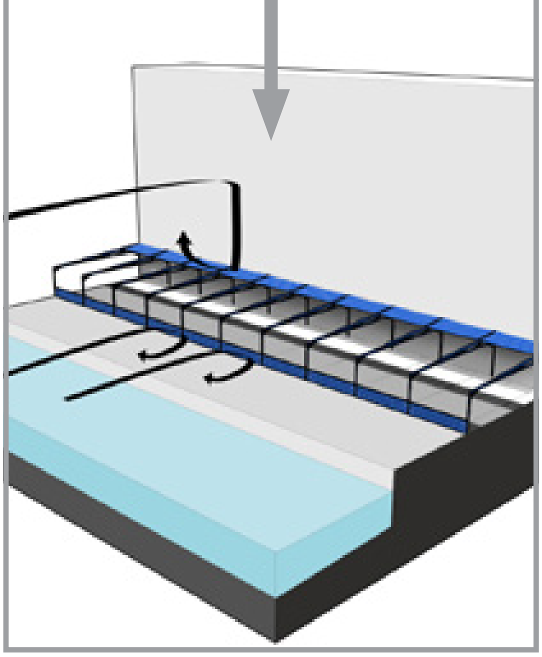


Figure 11.15: Flexible street cover winter

The third solution (figure 11.16) is a mix of flexible screens and the tailwind advantage design. This design is more flexible and costs less than the first solution. The third solution (figure 11.16) uses the wind better to provide extra tailwinds. It scores a bit lower on the no shading in cool conditions and light intrusion criteria. The cover from precipitation also scores a bit lower. Although this solution has a higher score than the first solution, it is not the winning solution. The second solution scores higher because of its simplicity and lower costs.

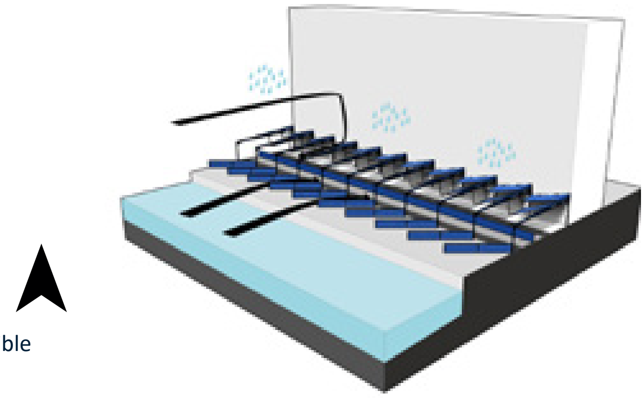
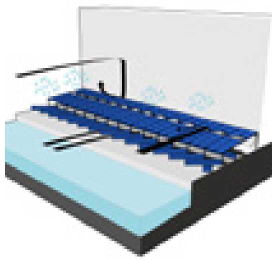
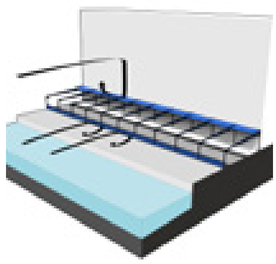
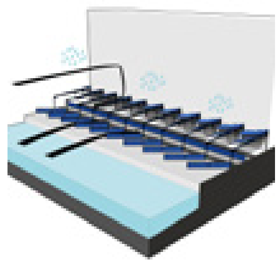


Figure 11.16: Flexible street cover with tailwinds

Test bed 	 Tailwind static roof	 Flexible street cover	 Flexible street cover & tailwinds
Wind			
Wind protection/diversion	+ +	+	+ +
Wind admission (warm con.)	+ +	+ +	+ +
Tailwind	+ +	- -	+ +
Less resistance	+ +	+	+ +
Shortwave radiation			
Shading ^24 °C	+ +	+ +	+ +
No shading under 15 °C	+	+	0
Light intrusion *	+ +	+	+
No glares	- -	+ +	+ +
Precipitation			
Cover direct impact	+ +	+ +	+
Safety / General			
Wide paths	+ +	+ +	+ +
Visibility for/of cyclists	+	+	0
Technical feasibility *	0	+	0
Costs *	-	+ +	0
Maintenance	+ +	+ +	+ +
Total Score	**69/85**	**73/85**	**70/85**

11.5 Open routes

The first solution (figure 11.17) is a combination of the best scoring open route solutions of RTD part I. The cyclist propelling vents are placed where cyclists have to cycle against slopes. These vents use the fast winds in the advantage of the cyclists. The sides of the bridge are covered with translucent panels. These translucent panels keep the view open and allow daylight to the cycle paths. The roof can be open during colder days without precipitation or fast winds. This design offers a good grading in the wind and the precipitation sections. But the scores are not optimal in the shortwave radiation section. The roof is closed for the most of the year, which means that during colder conditions it will be a bit darker. The technical feasibility and costs of this intervention are questionable and score low.

The second solution (figure 11.18) is a combination of the cyclists propelling screens and the flexible screens. The scores are almost similar to the first solution, but it does provide less tailwinds and the design narrows the paths. It is just a little bit more feasible due to its less complex constructions, but the first solution scores better at other criteria.

The first solution is the best combination of the two. Although this solution really helps cyclists to cycle more and easier, it is questionable if this kind of intervention is really realistic to implement on an existing bridge. Building the first solution on a new bridge would make it more cost efficient.

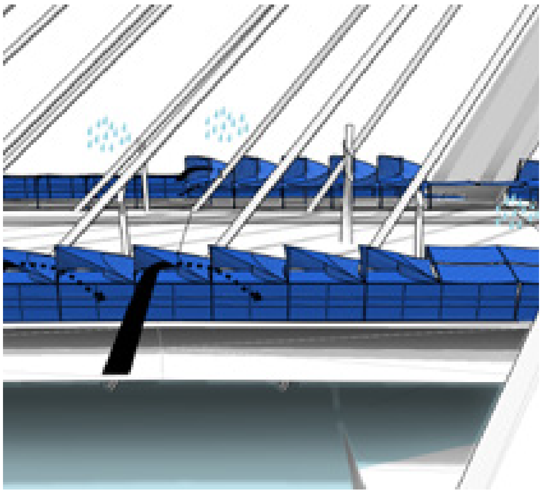


Figure 11.17: Wind funnelling roofing

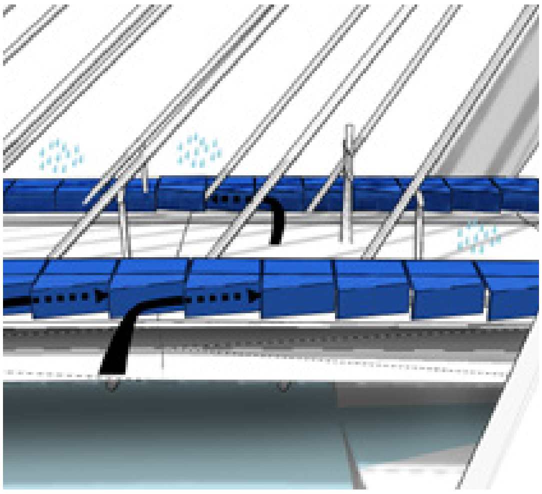
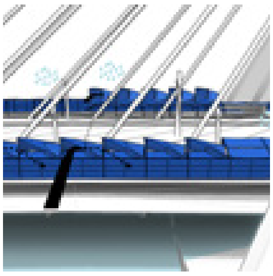
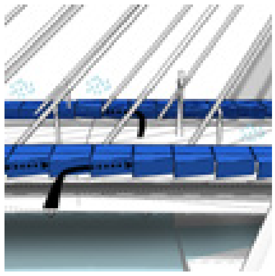


Figure 11.18: Tailwind walls and flexible cover

Test bed 	 Wind funnelling roofing	 Tailwind walls and flexible cover
Wind		
Wind protection/diversion	+ +	+ +
Wind admission (warm con.)	+ +	+ +
Tailwind	+ +	0
Less resistance	+ +	+ +
Shortwave radiation		
Shading ^24 °C	+ +	+ +
No shading under 15 °C	0	0
Light intrusion *	0	0
No glares	+	+
Precipitation		
Cover direct impact	+ +	+ +
Safety / General		
Wide paths	+	-
Visibility for/of cyclists	+	+
Technical feasibility *	- -	-
Costs *	-	-
Maintenance	+ +	+ +
Total Score	**62/85**	**60/85**

12. Implementation

This chapter elaborates on the highest scoring integrated design solutions and takes into account the psychological influences for thermal perception of cyclists. These psychological improvements are details added to the design solutions. Every test bed is elaborated in the form of an explanation in text and images such as an artist impression and sections of the solutions. In this way multiple situations could be shown (too warm, cold, precipitation or combinations). Discussed is how it should operate and where it is made of. This chapter provides the answer on the main question of this thesis: **Which solutions can improve the thermal perception of cyclists during uncomfortable weather situations (and how)?**

12.1 Crossings

The most important problems mentioned in chapter 5 were dominant winds from southwest direction, too much shade in winter (due to the tall buildings) and not enough shade in summer. Thereby do cyclists need to wait for the red light, which lowers their thermal comfort levels when the weather is not positively influencing the thermal perception of the cyclists (because they are longer exposed to unpleasant weather conditions). The psychological influences on thermal perception in order to increase the thermal perception of cyclists are good enough in the present situation, the new design only has to add some warmer colours in the palette.

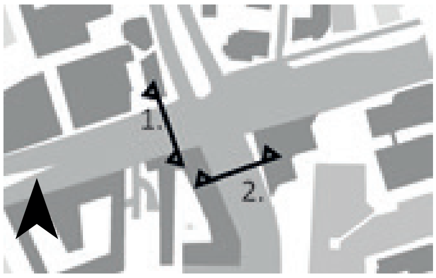
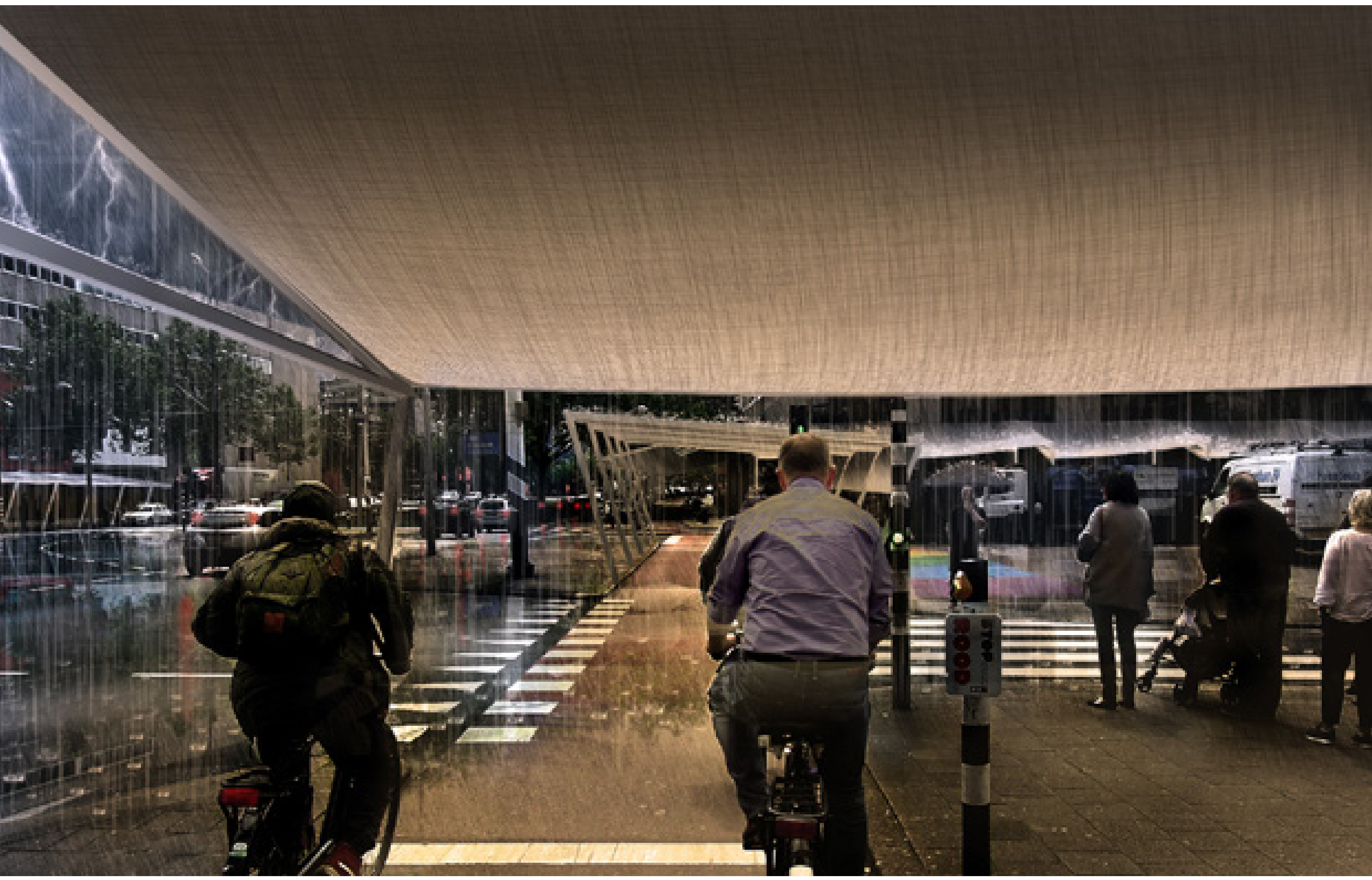


Figure 12.1 (below):
Artist impression crossings



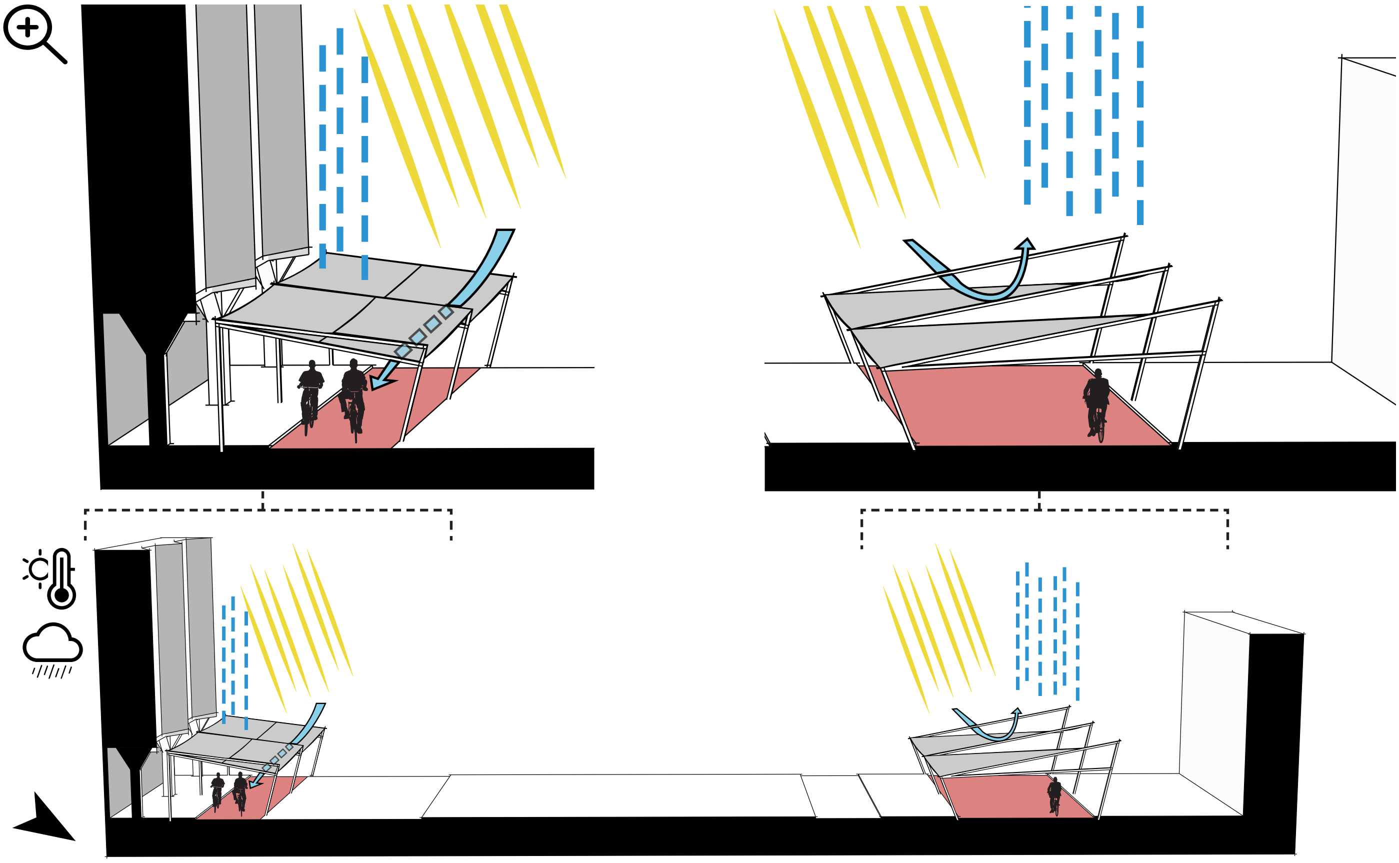
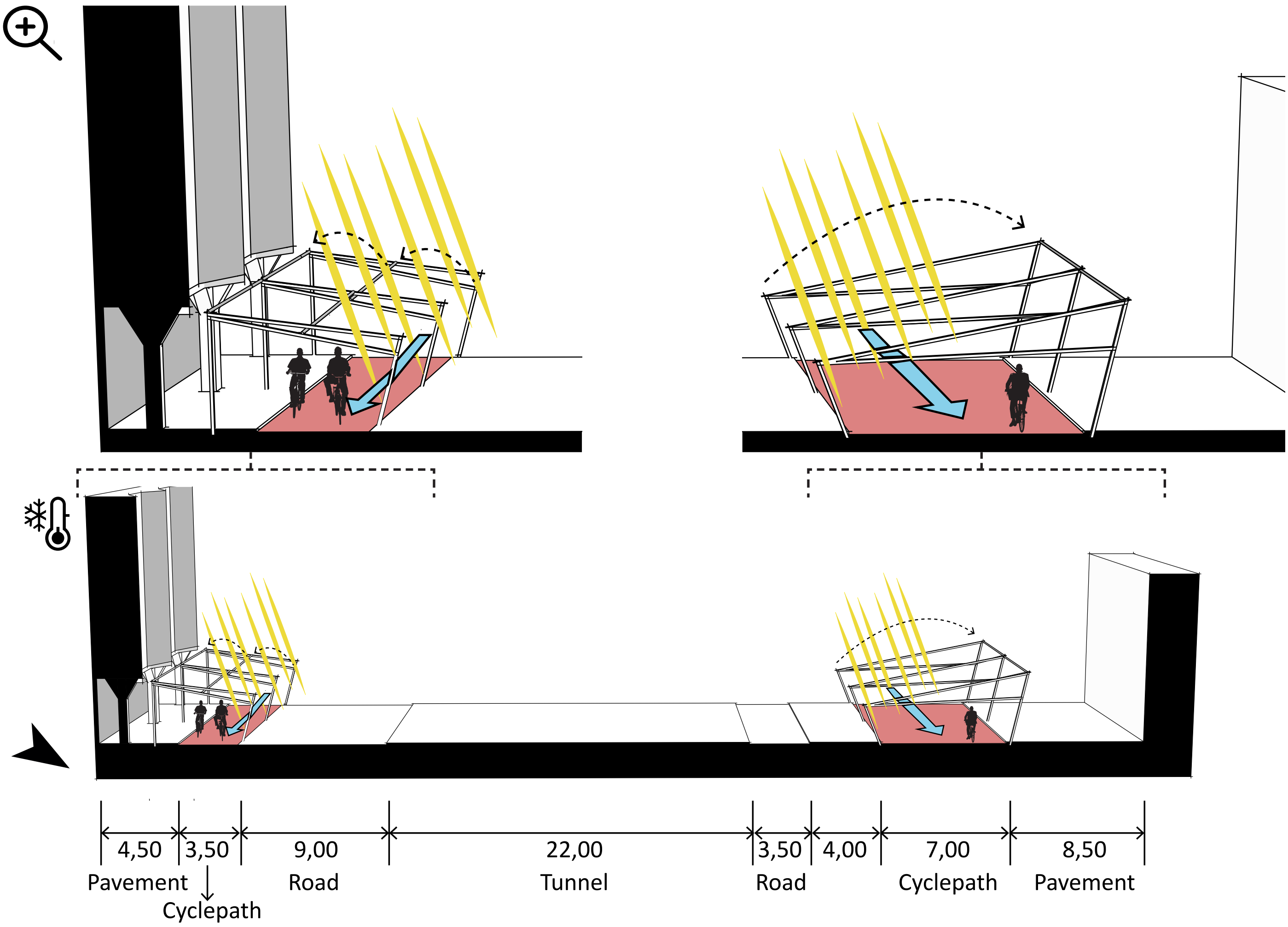


Figure 12.2 (above):
Section 1-A, Westblaak
and magnifications

Figure 12.3 (below):
Section 1-B, Westblaak
and magnifications



The integrated crossing solution is implemented in one of the problematic junctions of Rotterdam; the crossing of Westblaak-Blaak and Schiedamsedijk-Coolsingel. It is not possible to demolish the tall buildings around this crossing in order to allow more light during colder days, but the new design takes into account low light situations. The structures are completely open during colder situations without precipitation (figure 12.3, section1-B; temperatures below 24 C° without too much wind and precipitation).

The structures contain flexible screens made of flexible composite materials. These screens are woven from polyester cloth, coated/interwoven with a high performance polymer surface layer. The composite materials are completely weather proof and do not erode or degrade (Ferrari, 2017). These screens can be deployed when it starts to rain, hail, snow or when it is too warm to provide shade for cyclists. Figure 12.1 (heavy rain) and 12.2 (section 1-A; too warm or precipitation) displays this situation with the deployed screens for Westblaak.
The second section is taken at the Schiedamsedijk and is NNW directed. Cyclists need to be protected from southwest downwash winds from building façades. Figure 12.4 shows section 2-A, where the flexible composite screens are deployed and protect cyclists from; downwash winds, precipitation and too much shortwave radiation during too warm conditions.
The screens are folded when colder temperatures occur (below 24 C°) without precipitation (as seen at figure 12.5; section 2-B, cold conditions without precipitation).

It is possible to colour the composite material screens, a warmer tint may be chosen in order to provide a warmer colour palette during colder days (enough colder colours appear at these streets, see chapter 4.2.2). Straight forward forms are used to design the structure; form follows function. Post-modernistic materials are used to connect to the existing landscape. Many steels and glass materials are currently used at the crossing. Steel or aluminum are possible materials in order to make the structures.

The screens deploy or fold by a small motor which pulls the screens in the desired location. These motors are controlled remotely by making use of the 4G (mobile/satellite) or LoRa network (a new type of independent low frequency network in Rotterdam). The municipality is able to control these screens and position them in a desired direction, or this happens completely automatic by sensors which measure weather conditions (Bruines, 2017).

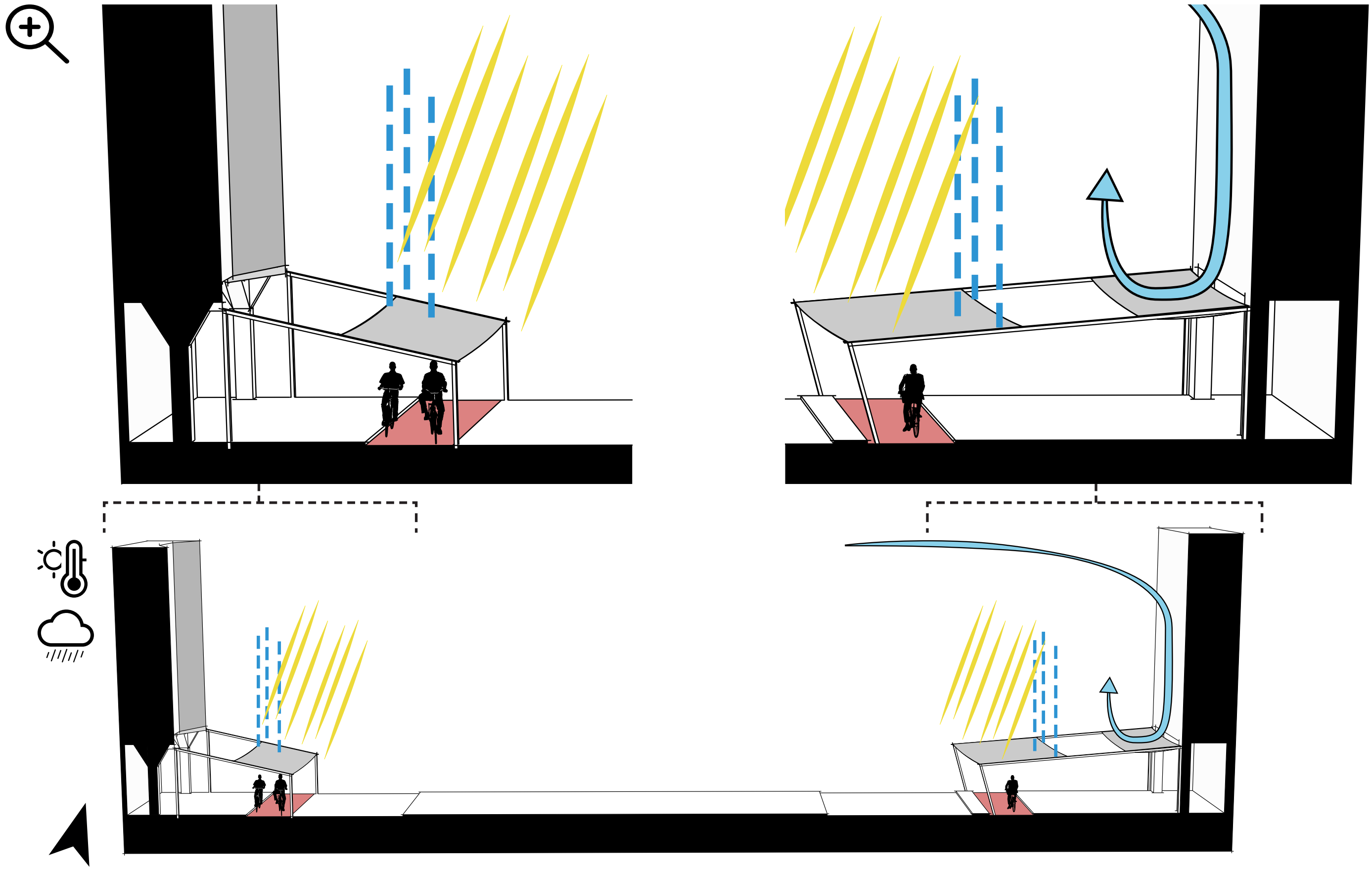
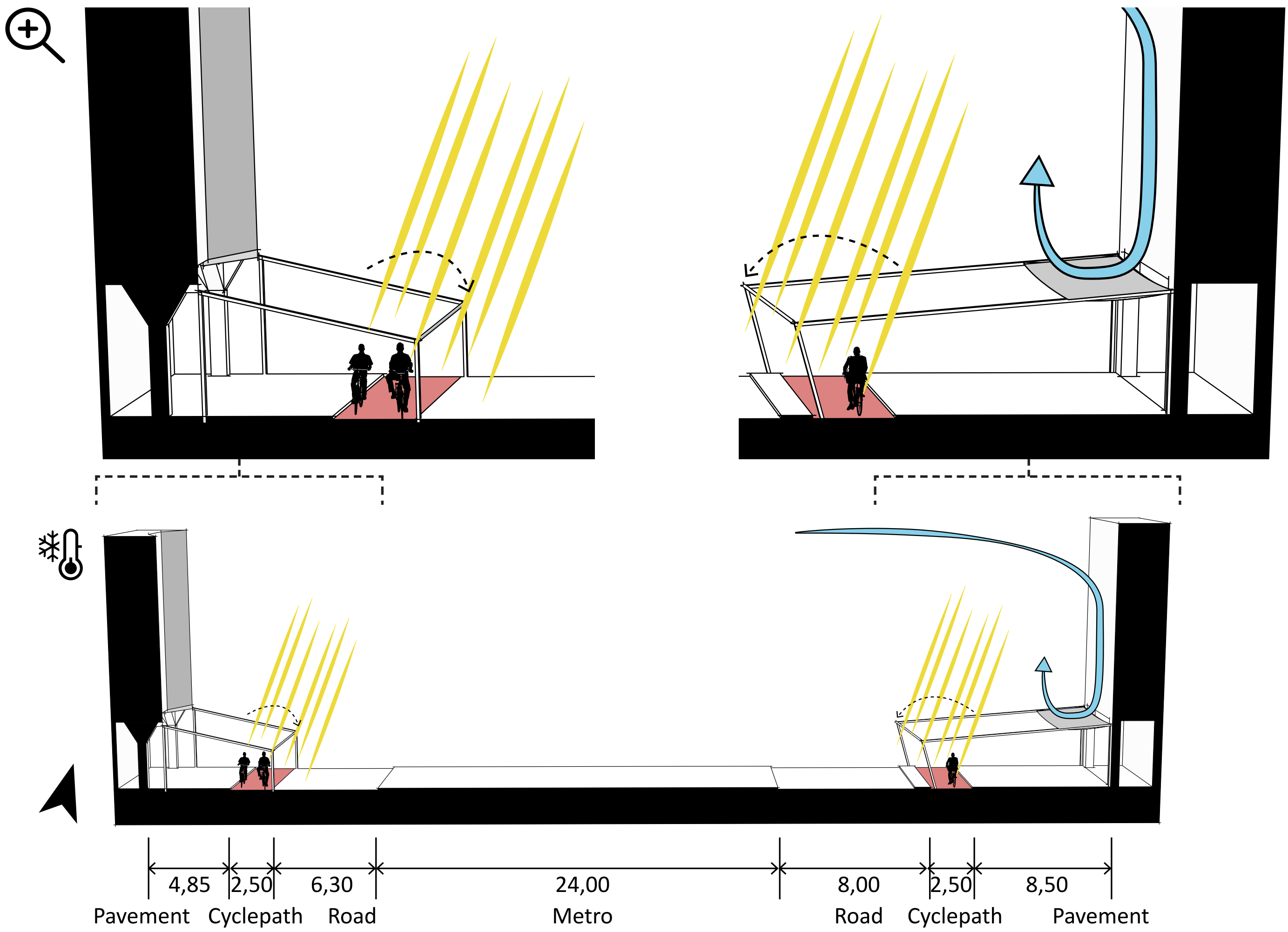


Figure 12.4 (above):
Section 2-A, Schiedamsedijk
and magnifications

Figure 12.5 (below):
Section 2-B, Schiedamsedijk
and magnifications



12.2 West-east routes

West to east oriented routes have several problematic issues; too much shortwave radiation during summer, and not enough shortwave radiation during winter. Wind forms a minor problem for these kind of streets, because it partly skips the street. It might be more problematic for cyclists during situations of SWW winds. Precipitation is a general problem for all street profiles. The street is quite boring in terms of colours, material use and detailing. The new design solution should include interesting forms and contrasting (cooler) colours during summer. The overall colour palette is quite warm, so winter situations are perceived more comfortable in terms of the psychological influences on thermal perception.

Shortwave radiation forms a dynamic problem; more shortwave radiation is required during colder situations (under 15 C°), but less shortwave radiation is desired during too warm situations (higher than 24 C°). Chapter 10 displays the solution with the photochromic roof as the highest scoring solution. This photochromic roof is already explained in chapter 8.1. The concept is simple; the glass provides shade during too warm situations (threshold on 24 C°, see figures 12.6 and 12.7) and there is no shading of the glass panels below this threshold (figure 11.8). This process happens thermally, so no extra energy is needed. The shading in the panels is coated with a blue tint, so during too warm days a cooling filter of blue light adorns the street. The panels are fully transparent during all other situations. The structures are made of hardwood, because of its strength and durability.

Wind is repelled by the roof structure, which is shaped in the form of sharp waves or ridges. The waves also create more surface roughness in order to slow down winds from SWW or west directions. Precipitation is guided to the sides of the roof and flows directly to the sewers. Cyclists are protected from too much shortwave radiation in warm situations, from cold winds during colder situations and precipitation for all situations with this solution.

Figure 12.6 (below): Artist impression west-east routes

The trees on the south side of the street may be partly cut down in order to allow more shortwave radiation during colder situations (below 15 ° C).

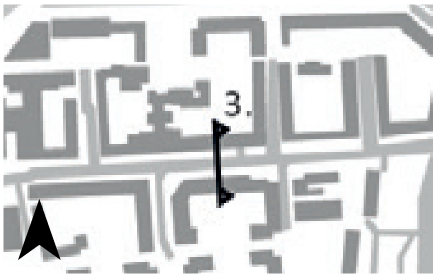
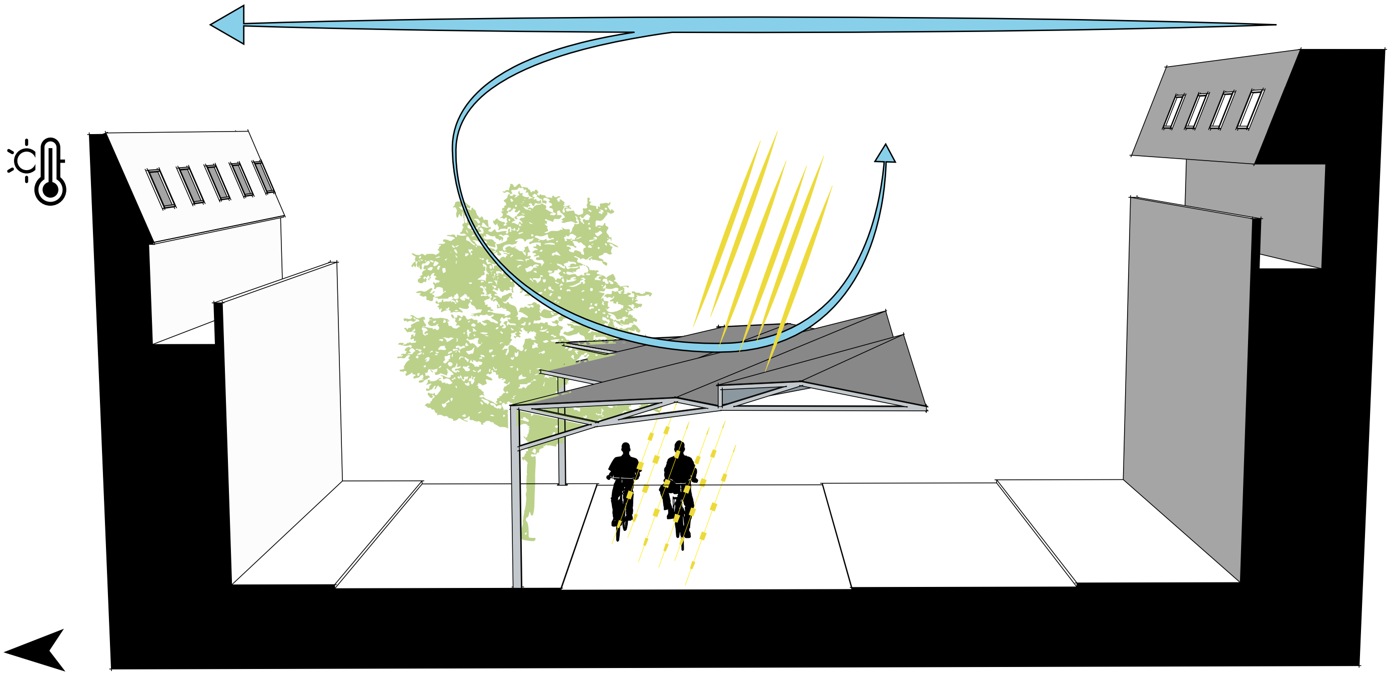
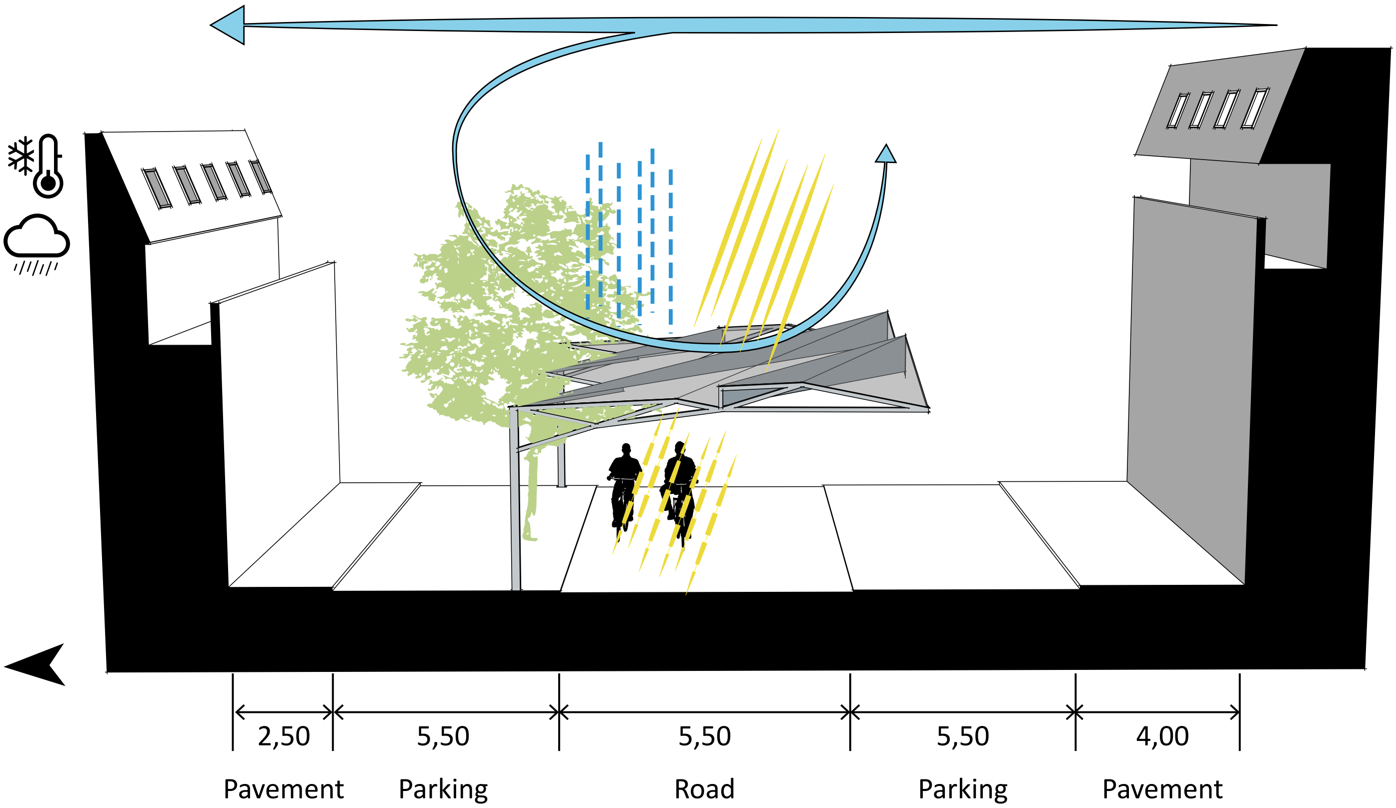


Figure 12.7 (below): Section 3-A, too warm conditions

Figure 12.8 (bottom): Section 3-B, too cold or/and precipitation





12.3 Southwest routes

Southwest routes have fewer problems for shortwave radiation than west – east oriented streets, but the wind problems are larger because of the street orientation (perpendicular to the main wind direction). Although this is not a problem if a cyclist rides to the northeast direction (because of the tailwinds). Precipitation problems are equal for the whole street. The overall colour palette is warm with many brown tints and the atmosphere of the street is friendly and lively.

The solution is a combination of the tailwind cycle path and the use of moveable photochromic panels. The photochromic glass functions the same as the glass of west – east routes; shaded during too warm situations (higher than 24 ° C) and transparent for all other temperatures below 24 °C (this process happens thermally). The glass is tinted with a blue colour, and therefore provides a cooler atmosphere during warmer situations (figure 12.9).

The panels on the south side of the street are moveable in a vertical fashion. The panels open on the southwest side to allow tailwinds (figure 12.10, right side). These panels are closed when it starts to rain, hail or snow to protect cyclists from incoming precipitation (figure 12.11). The movement is controlled by the municipality (4G or LoRa) or automatically via sensors. The photochromic panels on the opposite side of the street (north side) are fixed. Here, wind resistance needs to be diminished, which is achieved by a winding path along green panels. The green panels are constructed of fences covered with ivy. Ivy stays green throughout the year and therefore decrease wind resistance during the whole year. The roof on the north side of the street protects cyclists from incoming precipitation.

Figure 12.9 (below):
Artist impression
southwest route

The construction is made of hardwood and is shaped in a way that it fits the existing styles (a mixture of Neoclassic and Art Deco), with many arches, curves and detailing at the corners of the constructions. The structures are painted (warm-)white in order to connect to the style/ detail elements of the buildings along the street. The trees along the south side of the street need to be cut down, because they can not be combined with the new solution constructions. The trees on the north side of the street can stay and are interwoven in the new solution.

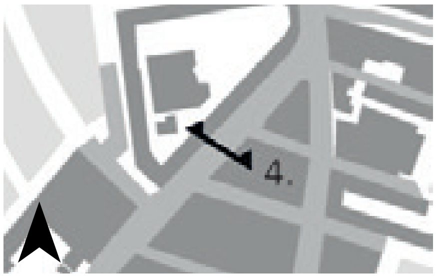
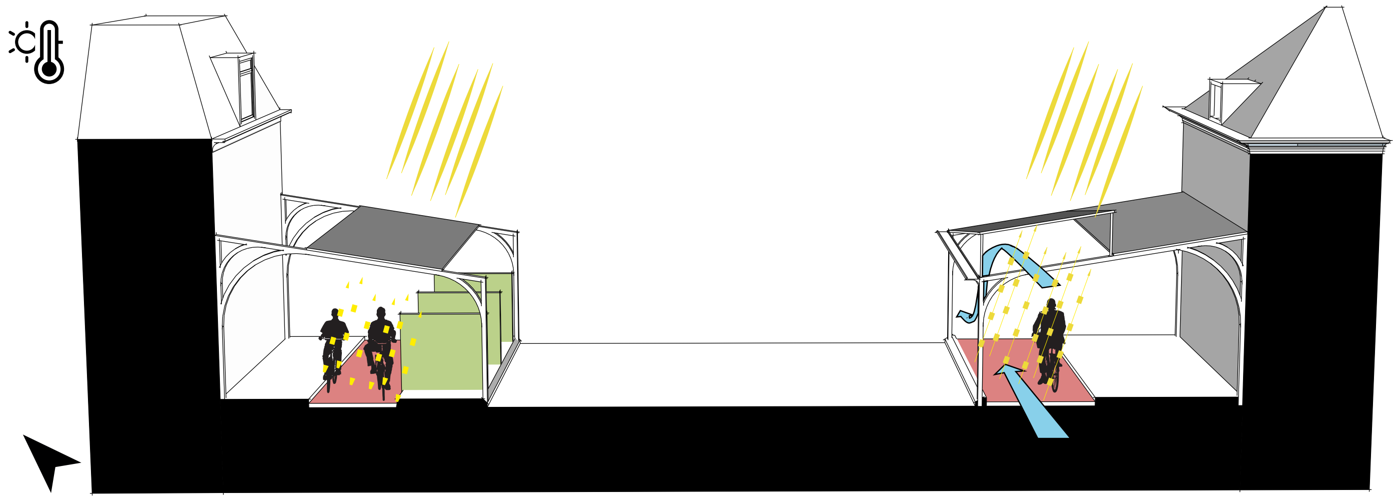
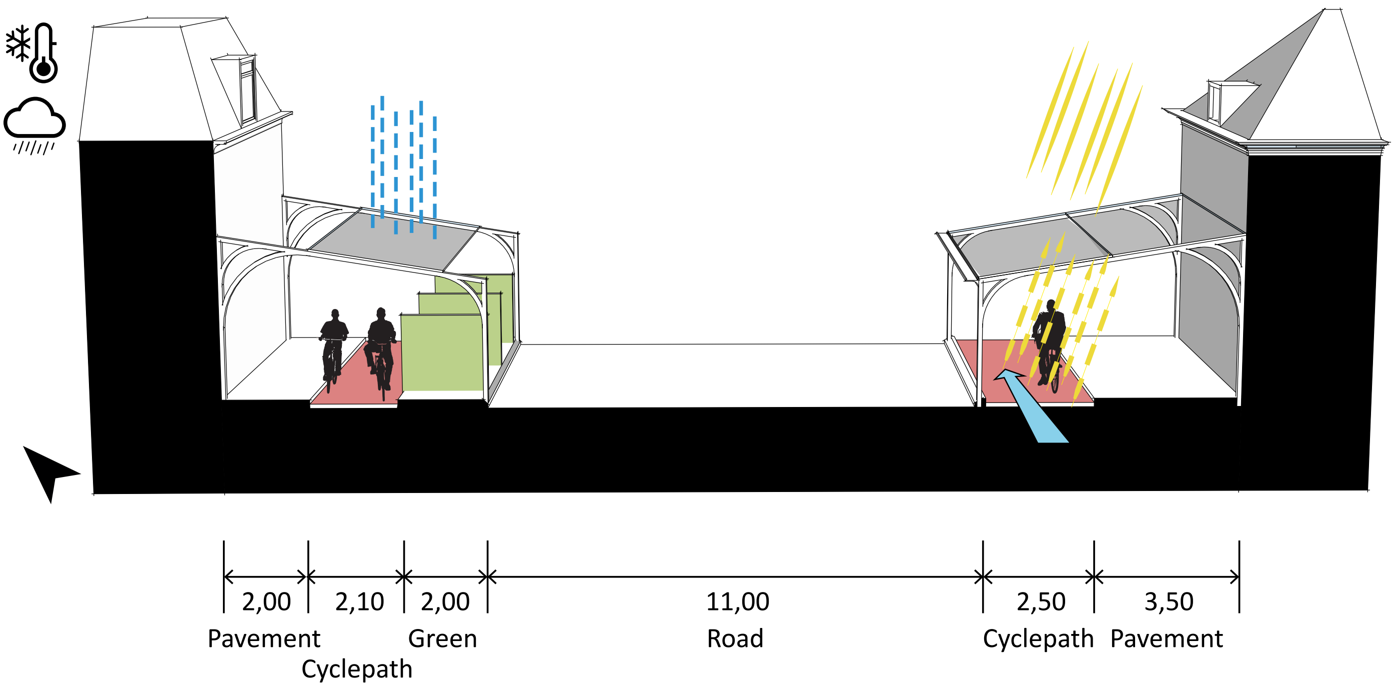


Figure 12.10 (below): Section 4-A, Bergweg, too warm conditions

Figure 12.11 (bottom): Section 4-B, Bergweg, cold conditions and precipiatation





12.4 Waterfront routes

Waterfront routes are less protected from weather influences than the earlier mentioned types. Wind creates gusty environments for cyclists and there is no shading during warmer days. Wind worsens the thermal perceptions of cyclists during colder days, but is able to cool down cyclist during warmer days.

The found solution is the answer on this dynamic problem; a construction with flexible screens. These screens may be moved in the desired positions according to the weather conditions. All screens except the side screen are folded during colder weather (under 15 ° C), to allow shortwave radiation and block side winds (figure 21.14). All screens can close when it starts to rain, hail or snow (figure 12.12). Cooling side winds in combination with shade create a pleasant thermal perception during too warm conditions. The side screen is opened and top screens are closed during this situation (figure 12.13). The screens can stay in this position during summer rain showers to allow more cooled air to the cycle paths.

The structures are made of hardwood, because of its strength and durability. The use of wood also adds a warm colour to the cool colour palette of streets such as Posthumalaan. Detailed elements in the corners are added in order to improve the somewhat boring atmosphere. The screens are made of the same composite material which is also used at the crossings. This material is very though, does not erode and is weather proof. These screens are tinted in a warmer colour to add warmer tints to the existing (overall cooler) colour palette and to contrast the water colour (which will create more vivacity in colours). The screens are operated remotely via the municipality (4G or LoRa) or automatically via sensors.

Figure 12.12 (below):
Artist impression
waterfront route

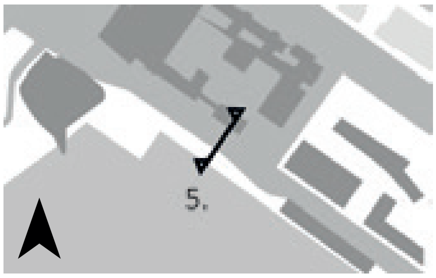


Figure 12.13 (below): Section 5-A, Posthumalaan, too warm conditions or precipitation

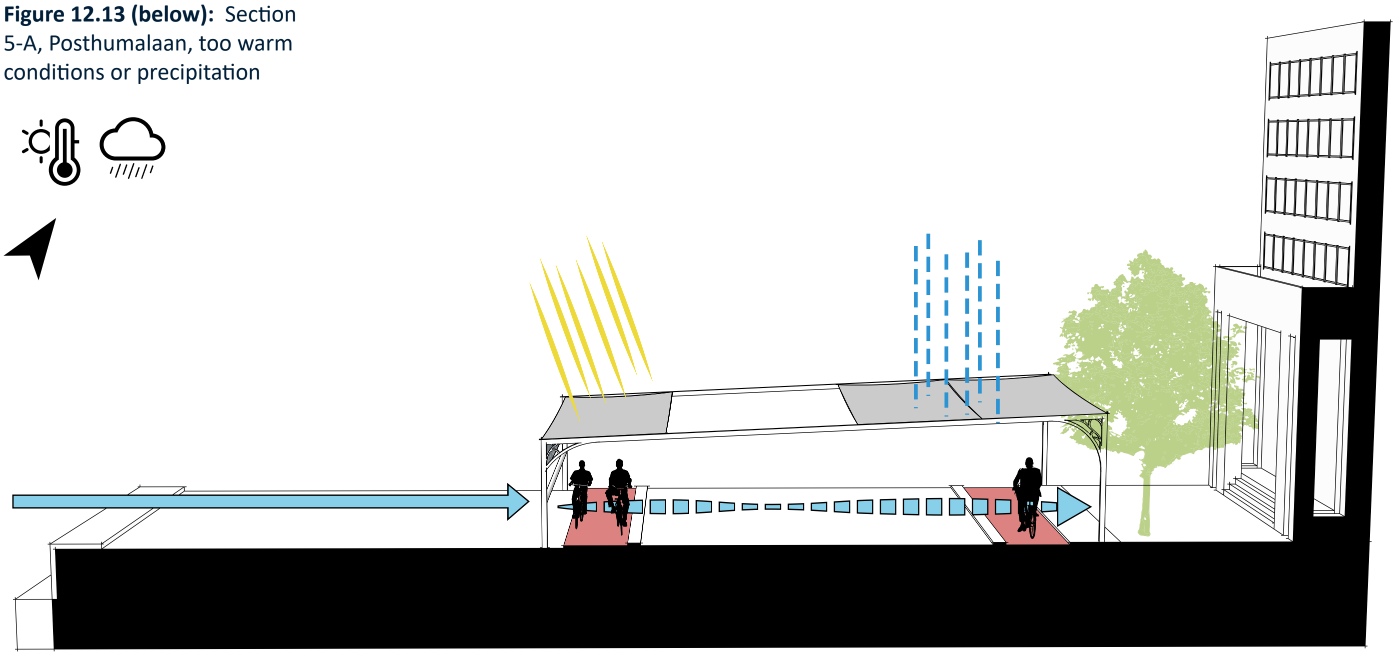
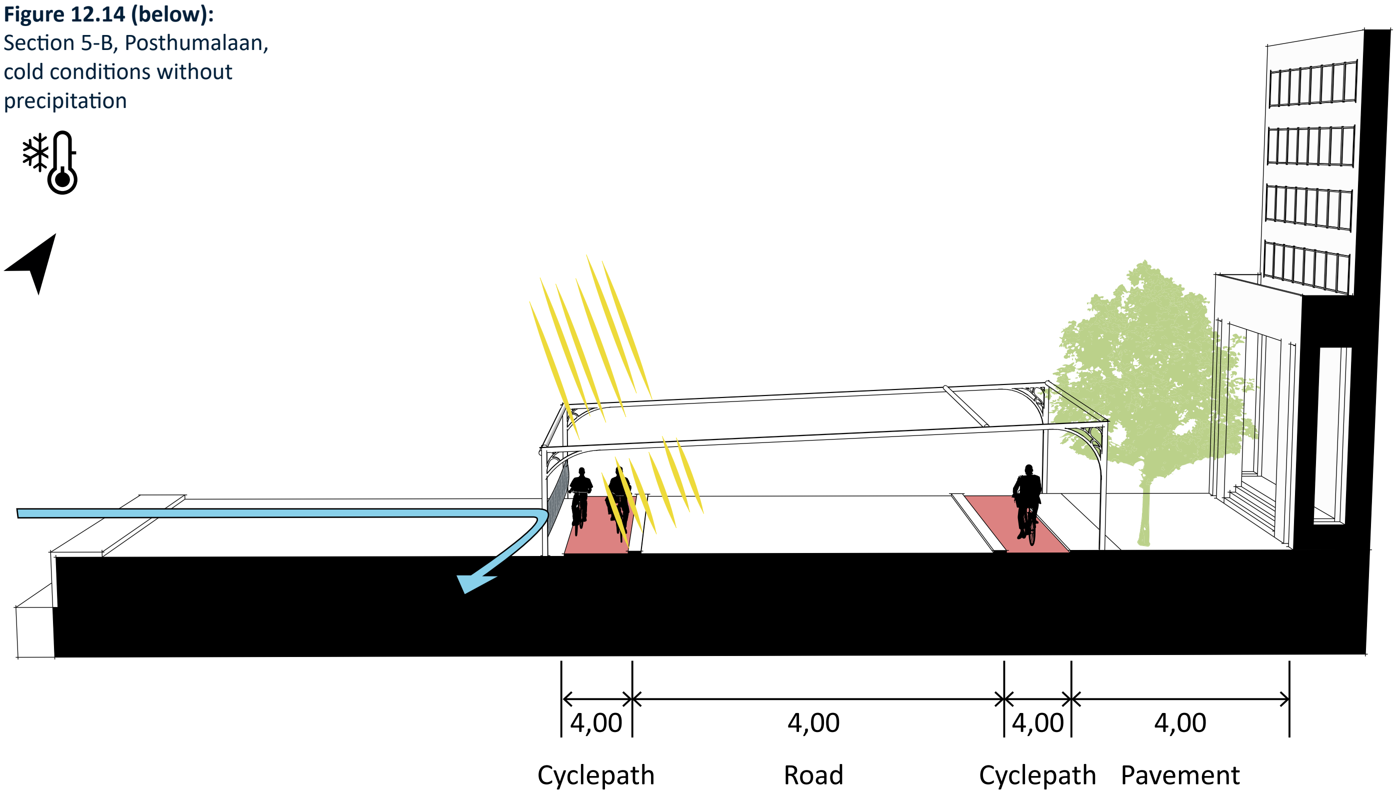


Figure 12.14 (below): Section 5-B, Posthumalaan, cold conditions without precipitation



12.5 Open routes

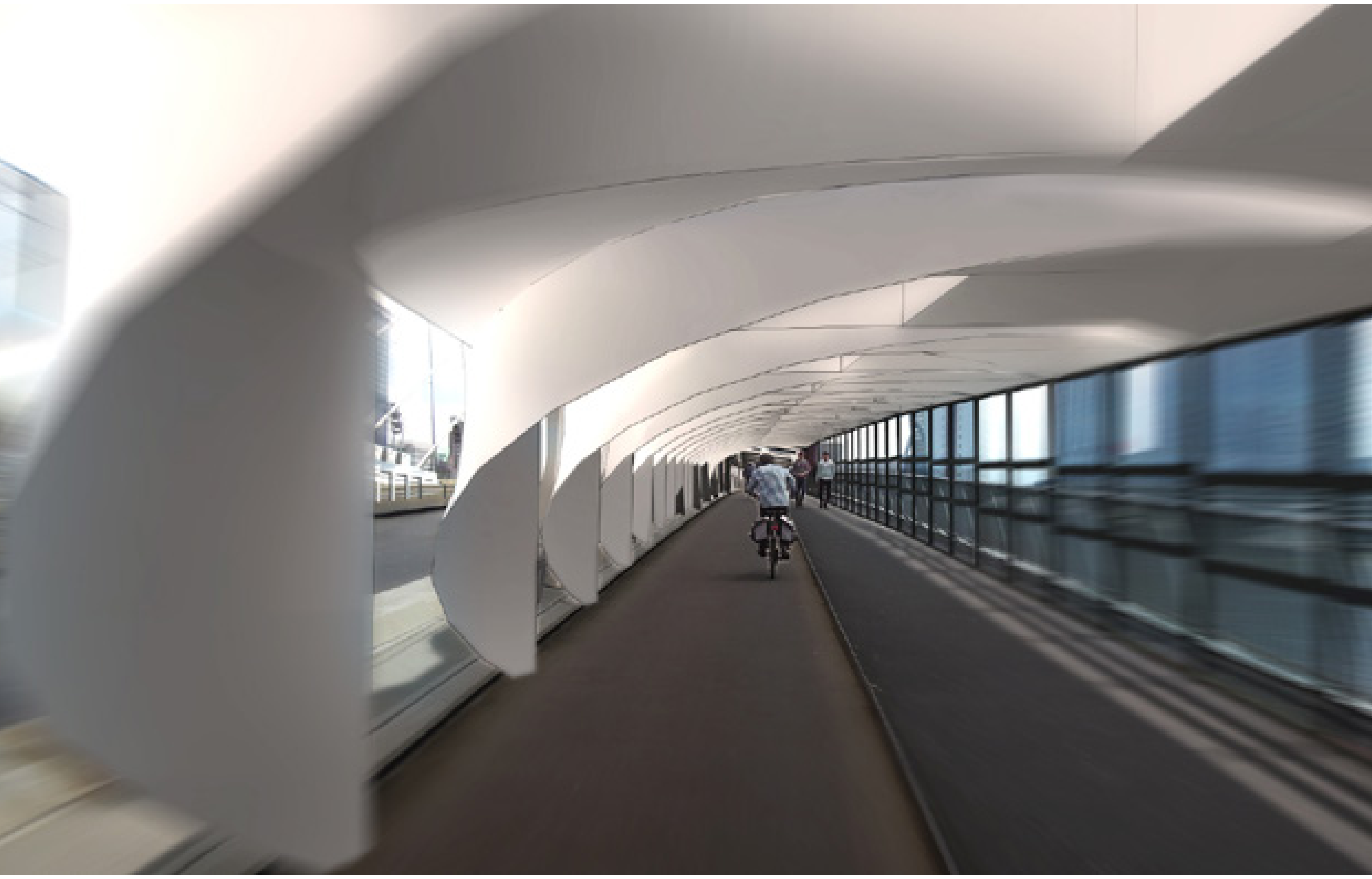
Open routes are completely open to all types of weather conditions. Therefore drastic solutions are used to design a thermally comfortable environment. First, section 6 (figure 12.16 and 12.17 right side), where the cyclists rides in southeast direction to the Wilhelmina pier and Kop van Zuid. The slope of the bridge causes the body of the cyclist to warm up and creates thermal uncomfortable situations in warmer days. It is almost impossible to climb upward the bridge during stormy weather.

But the wind could also be the friend of the cyclist as we learned from other solutions. A funnel collects the incoming winds and redirects them as tailwinds for cyclists. Cyclists are now pushed forward against the bridge. The funnels are no longer needed when the cyclists are rolling downwards the bridge (figure 12.18, right side), but the cyclists are still protected from too much wind, shortwave radiation and precipitation. These screens on top of the structure can be opened during colder days without too much wind or precipitation (figure 12.19, right side).

The cyclist has to climb the bridge again when he or she returns (Northwest direction). The cyclist is helped again by the power of the wind to climb the bridge slope (section 7) by a funnel shaped in the form of a volute, collecting wind and redirecting it in the desired direction (figure 12.18, left side). If the cyclist is pushed over the bridge it also crosses section 6 again (figure 12.16 and 12.17, left side). This construction functions the same as the earlier mentioned downhill event (figure 12.17 and 12.18).

The frames of the constructions are made of lightweight steels, such as aluminum. The remainder is covered with lightweight composite materials as mentioned in the solutions for crossings and waterfront routes. The moving screens (section 6 left side, section 7 right side) are also made of this composite material, and controlled remotely by the municipality (4G

Figure 12.15 (below): Artist impression open route



or LoRa) or automatically via sensors. Advised is to leave out extra colours or detailing to the constructions, because the constructions are already extravagant enough.

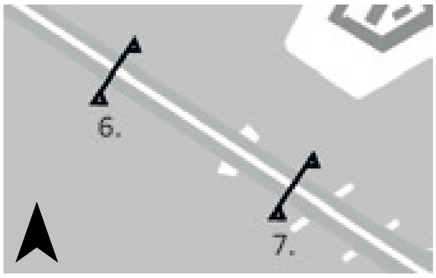


Figure 12.16 (below): Section 6-A, Erasmusbrug, hot or precipitation

Figure 12.17 (below 2): Section 6-B, Erasmusbrug, too cold conditions without precipitation

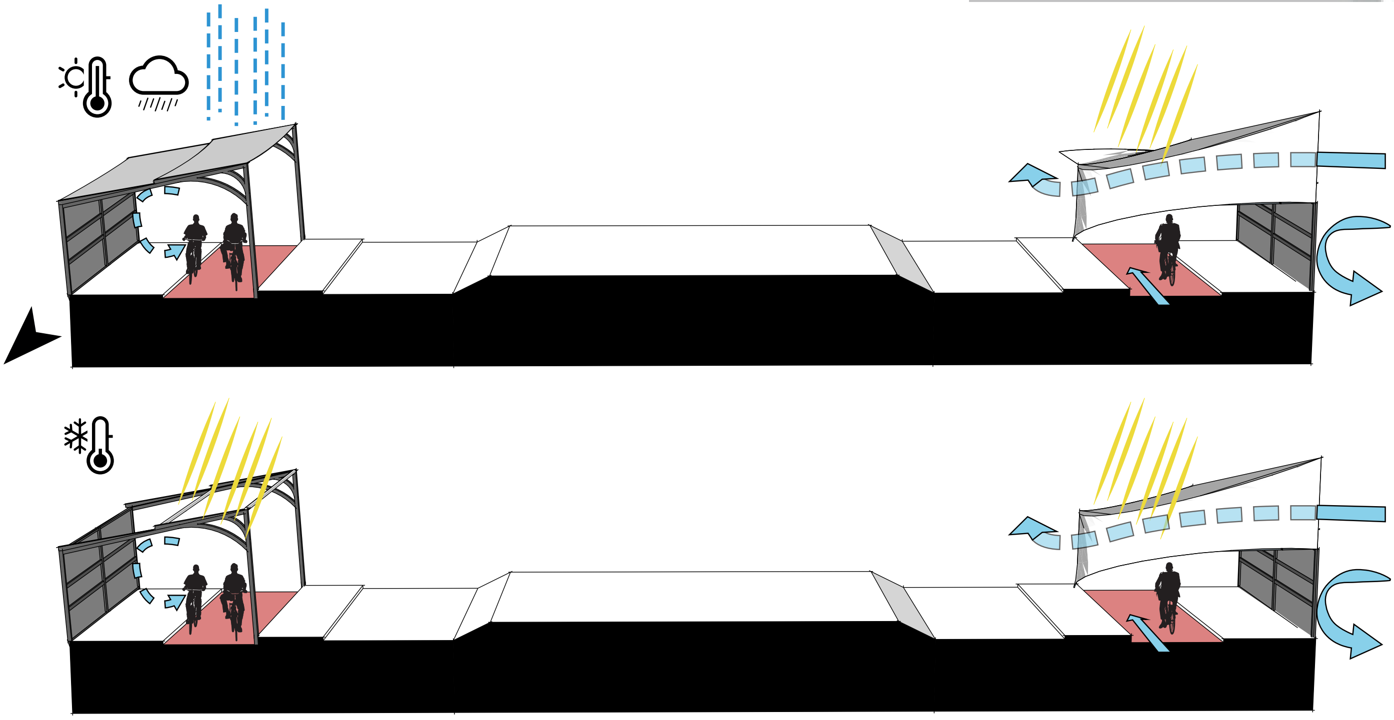
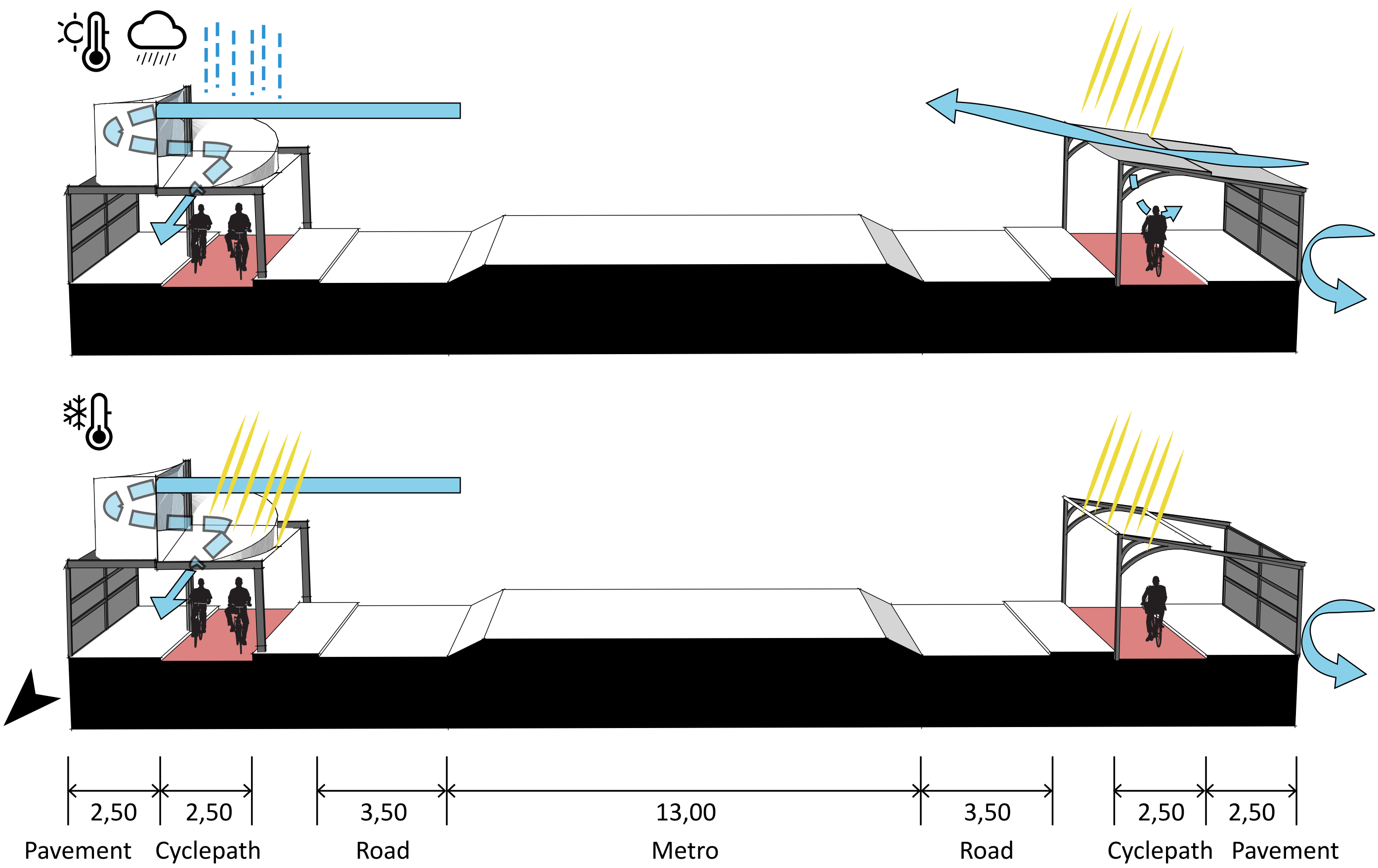


Figure 12.18 (below): Section 7-A, Erasmusbrug, hot or precipitation

Figure 12.19 (below 2): Section 7-B, Erasmusbrug, too cold conditions without precipitation



Epilogue

Concluding and reflective remarks are described in this part.

13. Conclusion

Nowadays many people suffer from diseases worldwide, in Europe the Non-Communicable Diseases (NCDs) are the leading cause of death and disability. They have an increasing strain on health systems and well-being, in particular people aged 50 years and older. Not only health is affected by these unhealthy lifestyles, but economic development as well (WHO, 2012).

Its proven that choosing active modes of transport has moderate benefits for health (Oja, 2011; Panis, 2011; WHO, 2003). The Netherlands provides the opportunity to improve people's health and lifestyle, because 28% of the people already use the bicycle regularly. However, people tend not to use the bicycle during uncomfortable weather conditions such as too warm weather (temperatures higher than 24 C°), too cold weather (temperatures under 15 C°) and precipitation (Böcker, 2014). Thereby does climate change worsen the already existing problem of less people using the bike during uncomfortable weather conditions. Rotterdam has the lowest bicycle use of all four big cities in the Netherlands and is used as the research area.
The main research question in order to find possible solutions for the mentioned problem is: **Which solutions can improve the thermal perception of cyclists during uncomfortable weather situations?**

Seven sub questions are stated in order to answer the main research question. This conclusion chapter describes the outcomes of these sub questions and finally a conclusion on the main research question is given.

(SQ1) What does influence the thermal perception of a cyclist?
Multiple elements influence the thermal perception of a cyclists, but not all elements could be solved by designing. The influences are separated in 3 main factors; internal physical/ physiological factors, external physical factors and psychological factors. The factors which could be altered by designing are;

- Internal physical and physiological factors: Tailwinds and diminishing wind resistance on cyclists can help to decrease metabolic rate, thus warmth from within the cyclists.
- External physical factors: Cyclists should be protected from wind during cold days, but wind is allowed during warmer days. Cyclists should be shaded for temperatures higher than 24 °C, no shading is needed when temperatures are below 15 °C. Cyclists should be protected from precipitation during colder situations.
- Psychological factors: The cyclists should receive as much shortwave radiation as possible, which means a good light intrusion is preferred to enhance pleasant emotional travel experiences. Factors such as company are also possible to facilitate as a landscape architect by designing wide paths. Cyclists can be manipulated in their thermal perception by altering the atmosphere.

(SQ2) Where along the problem routes, do certain influences cause bad thermal perception for cyclists?
Physical elements such as shortwave radiation and wind are analyzed in Rotterdam. Several problematic spots/routes are found for shortwave radiation; west –east routes are problematic for winter and summer situations, southwest routes are semi-problematic for both situations. Open and waterfront routes are fully exposed to shortwave radiation (positive effect in winter, negative effect during too warm situations) and crossings undergo major problems for shortwave radiation during winter and summer situations.
Multiple spots/routes are problematic for wind; southwest routes and crossings (or a combination) are the most problematic, especially when they are surrounded by high rise buildings.
Psychological problems are found at Posthumalaan and a part of Goudse Rijweg, which are the most inactive/less inviting routes of Rotterdam. Other routes (such as Bergweg, Schiedamsedijk and a part of the Boezemweg) are less problematic.

(SQ3) Which spatial configurations could be identified as problematic on the found uncomfortable routes?

All problem spots/routes are overlaid to identify the problematic spatial configurations. The problematic spatial configurations can be separated in 5 types; Crossings, west – east routes, southwest routes, waterfront routes and open routes. These problematic spatial configurations are transformed to generalized test beds in order to design solutions.

(SQ4) Which conditions must be considered while designing solutions for the problematic spatial configurations?

Important aspects are the criteria used for the assessment matrix and are categorized as; wind, shortwave radiation, precipitation and general/safety.

- The criteria for wind are: 'wind protection/diversion' (too cold conditions), 'wind admission' (warm conditions), 'Tailwind' and 'Less resistance'.
- The criteria for shortwave radiation are: 'Shading for temperatures higher than 24 °C', 'No shading under 15 °C', 'No glares' and 'Light intrusion'.
- The criterion for precipitation is: 'Cover direct impact'.
- The criteria for safety/general are: 'Wide paths', 'Visibility for/of cyclists', 'Technical feasibility', 'Costs' and 'Maintenance'.

The criteria are used to evaluate the solutions for the RTD part 1.

(SQ5,6 and 7) What are possible design solutions to improve thermal perception of a cyclist coping with wind, shortwave radiation and precipitation?

49 solutions are designed in order to answer these sub questions. The two highest rated designs per test bed (and per weather problem) are used fort RTD part 2. The highest rated solutions for wind (SQ5) have in common that they use flexible or moveable awnings, screens or trees to allow or repel winds and/or tailwinds for cyclists. Wind is used in the advantage of the cyclists and the wind is transformed in the desired direction. The highest rated solutions for shortwave radiation (SQ6) have in common that they give shade to cyclists when it is too warm (by panels, screens, photochromic glass or a green pergola). They provide as much shortwave radiation as possible when it is too cold (under 15 °C) by; folding the screens/ panels, transform transparencies of glass or by losing leafs. All solutions for shortwave radiation are designed with creating as much light intrusion as possible, without glares of the designed elements. All solutions for precipitation (SQ7) aim for protecting cyclists from direct impact of precipitation when it is desired by; panels, screens, pergolas or by completely covering streets.

(MRQ) Which solutions can improve the thermal perception of cyclists during uncomfortable weather situations?

The best scoring solutions for winds, shortwave radiation and precipitation are combined in integrated solutions. The best scoring (integrated) solutions improve the thermal perception of cyclists during uncomfortable weather situations for every test bed. These solutions are flexible in use and able to transform their appearance according to the weather situation at that time. The designs are implemented in existing situations of Rotterdam. Further detailing of these solutions are improving psychological (besides physical internal and external) influences that positively affects the thermal perception of the cyclist.

14. Discussion

This chapter discusses the significance and limitations of this research and will be separated in different parts; (1) reflection on the used methods (2)and a reflection on the synthesized results.

14.1 Reflection on the used methods

Literature is used to frame the research in a certain direction. The framing is limited since there is not a lot of literature about the topic available (chapter 1.6). Thereby, many concepts and solutions stated in literature are not tested in practice or/and real-life situations. The framing led to the choice of using the convergent parallel mixed methods.

The analysis (RFD) is separated in two parts; a qualitative and a quantative part. The use of this convergent parallel mixed method provided a broad overview/analysis of the complex problem, which could be seen as a strength of this thesis. Using this broad way of approaching the problem also delivers limitations to this research. A higher level of quantitative detailing in the analysis (RFD) was not reached, because there is a certain amount of time available. A higher detailed outcome of this analysis can be reached by using more advanced tools for analyzing the microclimate, such as Envi-Met or other digital analysis methods. Programs such as Envi-Met or Autodesk Flow Design (for wind patterns) are tried by the author, but are rejected for use in this research, because reliable input is needed in order to deliver reliable output. Thereby, these programs are subject to certain algorithms. While testing these programs for use, several errors were found in the algorithms of Flow Design, which made it obvious to reject the use of this program. Envi-Met could be a useful program to test outdoor environments, but is not used because its complexity and limitations in use. It might take an expert to do this, with a lot of available time, because all the mentioned routes need to be analyzed. Even though this is conducted, it will still not be perfect, the microclimate is very dependent on larger systems (such as the whole city of Rotterdam or even regional scale and larger). I learned a lot about wind patterns and flows by using these programs and by using literature of thermodynamics. This learning process enabled me to make educated guesses about the wind patterns and behavior in the urban fabric of Rotterdam. This provided rough, but sufficient renders of wind problems in Rotterdam.

Trimble SketchUp (2015/2016 edition) is a very easy to learn program and provides reliable outcomes for the shading analysis. Again, algorithms are used to calculate the outcomes of shading patterns in Rotterdam. The algorithm is quite reliable, because the user is able to adjust many parameters (such as time, date and location). SketchUp is recommended for further use in the field of practical microclimate science.
The qualitative part of this research is more subject to uncertainties then the quantitative part, because it especially relies on the view of the author, which is more subjective. Even though, the performed analysis is as objective as possible by using the methods of Jan Gehl. This analysis is a fast way to render a quite complete overview of the current atmospheres of Rotterdam's assigned problem routes.

The synthesis of solutions (RFD part 1 and 2) relies on an equal base of assessment. This equal base makes this thesis very reliable and serviceable for other researchers and practitioners of landscape and urban architecture. Others could use the same assessment matrix in order to evaluate their designs. The evaluation of the synthesized solutions is done by an individual and/or experts (peer debriefing (Creswell, 2014, p.202)) in the field of microclimate research and design. The solutions in this thesis are discussed with the mentioned experts, consisting; Sanda Lenzholzer, João Cortesão and the Climatelier (MSc thesis students with an urban microclimate topic). The use of this peer debriefing provides a more validate and accurate outcome than only relying on the judgement of the thesis's author. Although, the used method of assessing and testing is reliable, the originally designed solutions are based on the cognitive power of the author (biased by the author's background such as culture and education). This

means that maybe other individuals are able to process different solutions. The use of this method is recommended for further research and use in practice, because it delivers other (and thorough reasoned) designs than conventional methods of designing. The method is also fast in use, which made it possible to deliver a total amount of 64 (49 RTD part 1 and 15 in RTD part 2) designs in this thesis (and even more not published solutions).
The use of three iterations provides a detailed and accurate research product. The first iteration is a broad synthesis of solutions, which are applicable in a more general way. The second iteration combines the highest rated solutions of the first iteration phase, which resulted in integrated solutions. These integrated solutions still rely on generalized test beds (design laboratories with a controlled setting). Although, the solutions are still quite general, they provide a more detailed and complete answer to the complex problem. The third iteration phase implements the integrated solutions in existing situations. This implementation phase provide a detailed solution/answer to the stated problem.

14.2 Reflection on the results

The problematic spatial configurations are existing and generalized configurations. Generalizing these configurations makes the researcher able to deal with complex problems in a controlled setting. The assessment matrix sets an equal base for evaluating the products of the RTD phases. The used criteria of the assessment matrix are subject to the found literature and the decisions of the author of what might be important.

These synthesized solutions are evaluated with the use of this assessment matrix, which resulted in the shown solutions of RTD part 1 and 2. In general can be stated that the research product results in more architectural solutions than (green) landscape architectural solutions. This tendency is particularly caused by the used criteria of the assessment matrix. The criteria demanded solutions which are able to transform their appearance when desired; trees and other green are not able to lose their leaves or green features on demand. Trees have an optimal state when they are mature, but are not very effective during their growth, which can take up to 15 years or longer in urban environments. Trees also decay, which makes trees less constant in their efficiency and maintenance. Enough rooting space should be design in order to establish a properly working environment for trees. This extra space needed for trees, consumes other space, which might be needed for dedicated cycling infrastructure.
Last, this research is conducted on microclimate scale, which does not incorporate larger climatic systems. These larger systems might flourish by using large amounts of trees in larger designs such as parks, forests or urban green belts (Brown & Gillespie, 1995; Klemm, Heusinkveld, Lenzholzer, & van Hove, 2015; Lenzholzer, 2013).

This thesis tried to improve the economic burden and people's health by (mainly) preventing NCDs and promoting a healthier lifestyle. This might be reached for a small part of the total goal with the use of this thesis. The thesis focussed more on health than the economic burden, further research on the economic influences is recommended.
Recommended is to develop the stated solutions of this thesis in a more extensive research. This extensive research could also include criteria such as; air temperature and relative humidity. This research should be conducted on a larger scale (because of air temperature and relative humidity) and might take a large timeframe of research in account. Further research might be done towards designing solutions on larger scales (not only on microclimate scale), such as city, regional or even country scale. Imagine a whole country promoting a healthier lifestyle and environment by landscape architecture.

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Abstract

Nowadays many people suffer from diseases worldwide, in Europe the Non-Communicable Diseases (NCDs) are the leading cause of death and disability. They have an increasing strain on health systems and well-being. Not only health is affected by these unhealthy lifestyles, but economic development as well. Active modes of transportation could be the solution for this unhealthy lifestyle. Especially the Netherlands provides the opportunity to improve people's health and lifestyle, because 28% of the people already use the bicycle regularly. However, people tend not to use the bicycle during uncomfortable weather conditions such as too warm weather (temperatures higher than 24 C°), too cold weather (temperatures under 15 C°) and precipitation. Thereby does climate change worsen the already existing problem of less people using the bike during uncomfortable weather conditions. This thesis searches for solutions which can improve the thermal perception of cyclists during uncomfortable weather situations, for the city of Rotterdam. The Research for Design (RFD) shows that internal physical- and physiological-, external physical- and psychological factors influence the thermal perception of cyclists. This thesis found that these influences are the worst on certain spatial problematic configurations/test beds; crossings, west – east routes, southwest routes, waterfront routes and open routes. Separate solutions for wind, shortwave radiation and precipitation are synthesized for these test beds. The RTD method is used for finding new solutions and evaluating them on an equal base by using criteria. The criteria are subject to the most important elements of the RFD phase. The separate solutions of wind, shortwave radiation and precipitation are combined into integrated solutions, which form the second iteration of the RTD method. The best scoring (integrated) solutions improve the thermal perception of cyclists during uncomfortable weather situations for every test bed. These solutions are flexible in use and able to transform their appearance according to the weather situation at that time. The designs are implemented in existing situations of Rotterdam in order to provide a realistic research product.

Keywords: *cycling, weather, microclimate, thermal perception, design, health*