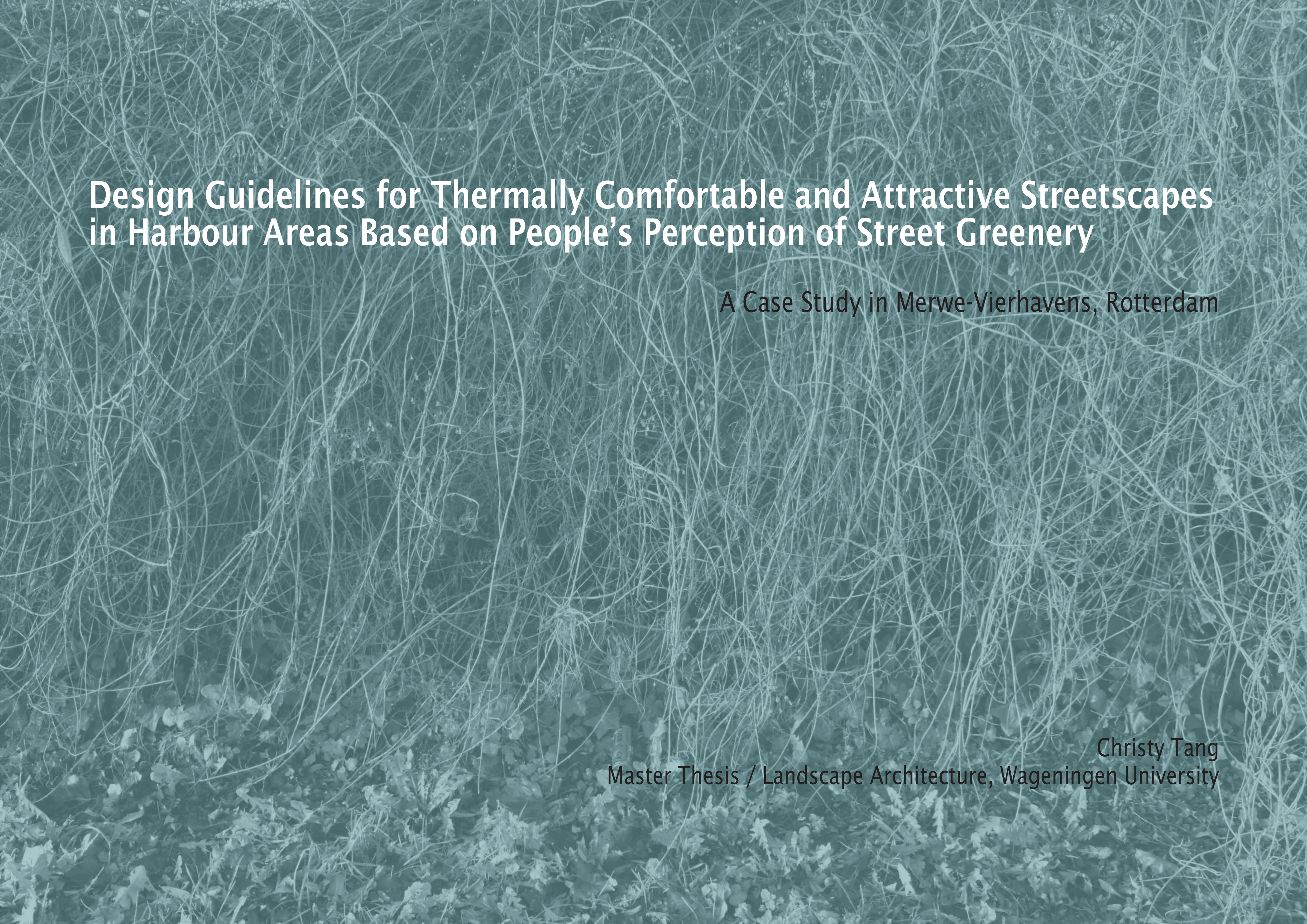


# Design Guidelines for Thermally Comfortable and Attractive Streetscapes in Harbour Areas Based on People's Perception of Street Greenery

A Case Study in Merwe-Vierhavens, Rotterdam

Christy Tang
Master Thesis / Landscape Architecture, Wageningen University

In collaboration with and supported by



Christy Tang
christysohanni@gmail.com


This publication is written as a fi nal master thesis in landscape architecture by order of the chairgroup of landscape architecture at Wageningen University.

Chairgroup Landscape Architecture
Phone: +31 317 484 056
Fax: +31 317 482 166
E-mail: office.lar@wur.nl
www.lar.wur.nl

Postbus 47
6700 AA, Wageningen
The Netherlands

In fulfillment of the requirements for the Master of Science degree in Landscape Architecture at the Wageningen University, Landscape Architecture Group

Supervisor: dipl.ing. Wiebke Klemm

.........................................................................

Examiner: dr.dipl.ing. Sanda Lenzholzer MA

.........................................................................

Examiner: prof.dr.ir. Adri van den Brink

.........................................................................

# Acknowledgements

The completion of this thesis has been a long journey and would not have been possible without the help and support of many people along the way.

First and foremost I would like to express my deepest gratitude to my supervisor, ***Wiebke Klemm***, for her guidance and the help to ground my research framework firmly by providing advice and insight throughout my work. I am grateful to Wiebke for giving constructive feedback on the content of this thesis and sharing her valuable experiences and knowledge. Furthermore, I would like to thank Professor ***Sanda Lenzholzer***, for her inspirations by giving creative ideas and precise comments.

I would also like to thank ***Marit Janse*** from the municipality of Rotterdam, who provided me with the opportunity to work in the ***municipality of Rotterdam*** and introduced me to the colleagues. I am grateful to Marit for her positive energy and inspiring conversations in the initial stages of this thesis, also for giving me essential information of the case study area Merwe-Virehavens that supports the research context for this thesis.

I am grateful to those people who participated the questionnaire surveys and contributed to the research process of this thesis by sharing their experiences and ideas.

Finally, I would like to thank my parents and elder sister for their faith in me and encouraging me to challenge myself. This thesis would not have been possible without their emotional support, patience, love and encouragement.

# Abstract

People are increasingly moving to cities for pursuing new opportunities and better quality of living and working environment. It is estimated that by 2050 almost 70% of the world population will live in cities (United Nations, 2014). Meanwhile cities are constantly undergoing changes in response to the processes of deindustrialisation, urbanisation and ongoing global warming. Climate change raises environmental issues such as urban heat island that affects human health and well-being. Re-development of harbour sites into new living and working areas is a well-known example for urban densification worldwide. Therefore, the challenge for landscape architects and urban planners today is to deal with the heat stress associated with climate change and urbanisation by developing thermally comfortable and attractive streetscapes in harbour areas to ensure health and well-being of new citizens.

Urban vegetation positively affects people's perceived thermal comfort and at the same time enhances aesthetic appreciation of outdoor spaces. Earlier studies demonstrated improved perceived thermal comfort through vegetation elements like trees and front gardens in residential streets (Klemm et al., 2015b). The spatial context of a harbour area, yet has not been the focus of a study. However, landscape architects need to know how to optimally re-design streetscapes by means of street greenery in order to improve perceived outdoor thermal comfort and attractiveness in harbour areas.

This thesis aims to develop empirical-based design guidelines for thermally comfortable and attractive streetscapes in harbour contexts. To reach that aim, questionnaire study in the form of online and face-to-face surveys were applied to investigate the impacts of different types of street greenery on people's long-term thermal perception and aesthetic appreciation. The questionnaire surveys were conducted in the city of Rotterdam, the Netherlands, in 2014. Within four harbour functional zones (port-industrial; new business; residential; residential waterfront) four alternatives of greenery types (no vegetation, ground vegetation, wall vegetation, trees) were visually evaluated by local people (N=106). Survey data was analysed by using descriptive statistics (i.e. Borda count) and qualitative content analysis methods (i.e. thematic coding and categorising).

The research findings indicate a positive impact of street greenery on long-term thermal comfort and attractiveness in a harbour area, which is in line with earlier studies. From all investigated greenery types, 'trees' was top-ranked for improving perceived thermal comfort (mean 3.84) and attractiveness (mean 3.68) on a scale range of 1-4; whereas 'no vegetation' in all zones was ranked lowest. 'Ground and low-height vegetation' and 'wall vegetation' was evaluated similarly for both aspects.

Based on the survey results, it is recommend to use different types of street greenery, especially trees combined with other green elements, to design the streetscapes according to harbour functional zone.

The results show that in port-industrial area and residential waterfront survey respondents valued 'open views' and 'harbour characters' with limited paved surfaces through ground and low-height vegetation; whilst trees can be used for visual screening to mask unpleasant industrial scenes. In new business area green walls and green façades should be implemented to create 'modern, colourful and inviting' atmosphere which is considered as attractive and suitable for a business district. The combination of large trees and flowers should be applied to diversify the residential areas that enhances thermal comfort and attractiveness of the neighbourhood.

The results of this thesis support landscape architects and urban planners to plan suitable types of street greenery within various harbour functional zones. By applying the design guidelines in former harbour contexts new living and working areas with thermally comfortable and attractive streetscapes can be created. That way, we contribute to the redevelopment of harbour areas being converted into more liveable urban environments in growing cities.

Photo credit: Anthropologie. Elmslie Osler Architect.
Retrieved from http://www.eoarch.com/index.php?id=27

# Table of Contents


## 1. Introduction

**Overview** 1

**1.1 Research Context** 2
1.1.1 Post-industrial urban development in contemporary world port cities 2
1.1.2 Shift towards climate-adaptive cities 3
1.1.3 Vegetation as an instrument for designing a comfortable urban street 3

**1.2 Problem Statement** 4
1.2.1 Heat stress in port cities 4
1.2.2 Urban heat island in the Netherlands 6
1.2.3 Human thermal comfort 6
1.2.4 Attractiveness of living and working environment in harbour areas 7

**1.3 Research Framework** 8
1.3.1 Knowledge gap identification 8
1.3.2 Research objective and research questions 9

**1.4 Research Design** 11
1.4.1 Philosophical worldviews 11
1.4.2 Research methods 12
1.4.3 The relationship between research and design 13
1.4.4 Case study area 14
1.4.5 Relevance and target audience 16

**Reference** 17

## 2. Theoretical Background

**Overview** 21

**2.1 The Concept of Urban Waterfront Regeneration and Harbour Redevelopment** 22
2.1.1 Port-city interface 22
2.1.2 Common development orientations 23

**2.2 Urban Heat Island and Thermal Comfort** 24
2.2.1 Scales and types of urban heat islands 24
2.2.2 Outdoor thermal comfort 27
2.2.3 Causes of urban heat island formation and the heat mitigation measures 30

32

**2.3 Benefits of Different Types of Urban Vegetation on Thermal Comfort and Attractiveness of Outdoor Spaces**
2.3.1 Physical and psychological functions of urban vegetation 32
2.3.2 Topology of urban vegetation 34
2.3.3 Ground and low-height vegetation 35
2.3.4 Wall and roof vegetation 36
2.3.5 Trees 37

**2.4 Effects of the Interaction between Urban Built Form and Vegetation on Thermal Comfort in Street Canyons** 38

**Reference** 40

## 3. Questionnaire Study


**Overview** 45

**3.1 Methods and Materials** 46
3.1.1 Questionnaire design 46
3.1.2 Participant (sample group) 51
3.1.3 Data collection 51
3.1.4 Data analysis 53

**3.2 Questionnaire Results and Discussion** 54
3.2.1 Response outcomes 54
3.2.2 Survey respondents 54
3.2.3 People's preferences in terms of thermal comfort and attractiveness considering the role of different types of street greenery 55

**3.3 Limitations and Critical Reflections of the Study Design** 64

**Reference** 66


## 4. Design Guidelines


**4.1 General Design Guidelines** 69
**4.2 Design Guidelines and Recommendations for the Four Harbour Functional Zones** 71


## 5. Case Study: Merwe-Vierhavens, Rotterdam


**5.1 Background Analysis** **73**
5.1.1 A brief overview of port-city developments in Rotterdam 73
5.1.2 The project 'Stadshavens Rotterdam' 74
5.1.3 Site selection: Merwe-Vierhavens, Rotterdam 75

**5.2 Site Analysis** 76
5.2.1 Heat stress 76
5.2.2 Street types 76
5.2.3 Green structure and typology of green spaces 78

**5.3 Implementation of Design Guidelines** 79
5.3.1 Port-industrial area 81
5.3.2 New business area 83
5.3.3 Residential area 85
5.3.4 Residential waterfront 87

**Reference** 89


## 6. Conclusion & Recommendations


**6.1 Conclusion** 95
**6.2 Recommendations for Further Research** 99
**6.3 Reflection** 100

**Reference** 101

**Appendix I:** *103*
Research through designing: the process of developing the visualisation images for the questionnaire

**Appendix II:** *108*
Questionnaire

**Appendix III:** *114*
Keywords provided by survey respondents for their preferences in relation to thermal comfort and attractiveness

**List of Figure** *118*

**List of Table** *120*

Photo credit: Miroslava Brooks. (2012). Tokyo urban Farm. Retrieved from http://www.miroslavabrooks.com/travelog/2012/06/21/day-18_tokyo_urban-farm

# 1 Introduction

1

Introduction

**Overview**

This chapter is divided into four sections in order to give an overview of the subject and provide background knowledge which is essential before entering the main chapters.
Section 1 describes the general research context on a broader scale, what is happening in contemporary cities worldwide and what are the environmental challenges we, as a landscape architect as well as the city dweller, may encounter in the near future. Section 2 focuses on the negative impacts of heat stress on the development of cities and particularly in the harbour area. It covers issues concerned with outdoor thermal comfort and attractiveness. Furthermore, the problems associated with urban heat island in Dutch context are briefly depicted in this section. Section 3 outlines the framework of this research with the identification of knowledge gap, definition of research objective and corresponding research questions. Section 4 presents the methodology and states how the research was undertaken. Besides, the case study area and target audience are addressed to explain how this thesis related to the real world and contribute to ongoing urban plans.

## 1.1 Research Context

### *1.1.1 Post-industrial urban development in contemporary world port cities*

The redevelopment of harbour area is a common phenomenon in port cities around the world. Cities historically have been built close to the water for transportation and connectivity purposes, and consequently port industries were developed and became the pillar of local economy. However, due to the migration of port activities and economic restructure. Many spaces left unused in the harbour areas, so-called spatial leftovers from the traditional heavy industry in the late 19th and 20th centuries which deteriorates environmental quality.

In response to deindustrialisation since the beginning of the 21st century and the increase in urban population, those former harbour sites are developing as new living and working areas with great potential.
Today, many port cities are experiencing transition from industrial to post-industrial times; the former is concentrate on function-oriented expansion of harbours to support economic growth, the latter is focus on mixed-use development of different urban functions to keep balance between living and working environments, and in the meantime to ensure the environmental quality. The new developments take geographic advantage of the harbour areas and often tend to build attractive housing and call for new forms of business, especially high-tech production and environment-friendly companies. This opens up opportunities for creating innovative and healthy cities that interests landscape architects, urban planners, business investors, high-skilled workers, and city dwellers.

Figure 1.1 Redevelopment of former port area for new city district; HafenCity Hamburg, Germany (Photo credit: KCAP Architects & Planners)

Figure 1.2 From industrial area to sustainable city; Western Harbour Malmö, Sweden (Photo credit: http://ecocitylab.org/)

### *1.1.2 Shift towards climate-adaptive cities*

Cities contribute to its own climate and at the same time affected by the climatic conditions. The interaction between cities and climate is crucial for citizens' health and well-being since it influences how people use public spaces and experience the weather (Kleerekoper et al., 2012; Nikolopoulou & Lykoudis, 2006).

Most of the cities are confronted with environmental issues relating to climate change. Approximately 70% of the largest and most populated cities in Europe are located in the coastal zones and have areas that are vulnerable to weather and climate extremes such as flooding and heat waves (World Bank, 2010).

Climate change affects the quality of life in cities both directly and indirectly through the presence of extreme weather events. For example, the occurrence of weather-related natural disasters cause environmental damages and have negative effects on energy consumption; whilst the unpleasant weather conditions put human and ecological health at risk as well as hinder urban development (Moonen et al., 2012; Eliasson, 2000). Therefore, for landscape architects and urban planners today, the primary task is to design cities that are more adaptable to climate change and less vulnerable to the threat of extreme weather events. Also, cities with comfortable climate supports the development of healthy and enjoyable urban environments.

### *1.1.3 Vegetation as an instrument for designing a comfortable urban street*

Urban vegetation has been proved that positively affects pedestrians' thermal comfort (Klemm et al., 2015ab; Bowler et al, 2010; Dimoudi & Nikolopoulou, 2003; Shashua-Bar & Hoffman, 2000) and at the same time enhances people's aesthetical appreciation of outdoor spaces (Klemm et al., 2015ab; Qin et al., 2013; Lafortezza et al., 2009; Smardon, 1988; Smardon, 1988; Ulrich, 1986). Besides, vegetation is a relatively feasible measure to improve comfort conditions and aesthetic experience in terms of cost and flexibility in adapting to existing built environment (Gill et al., 2007; Smardon, 1988). Hence, vegetation has a significant role to play in urban planning process and widely applied as a potential instrument for developing thermally comfortable and attractive streetscapes.

Figure 1.3 Using street trees and vegetation in the design of urban streets and pedestrian areas; Downtown Seattle, Washington, USA (Photo credit: http://www.seattle.gov/)

## 1.2 Problem Statement

Climate change is a fact of life in our world. Extreme heat associated with climate change is giving rise to worldwide concern, which is an urgent issue that exists in most of the modern cites and directly affects humans and the environment in many ways. This research focuses on heat-related problems which are threatening the quality of people's life. Thus the following sections define the problems with respect to outdoor human thermal comfort and attractiveness of urban streets, particularly in harbour areas.

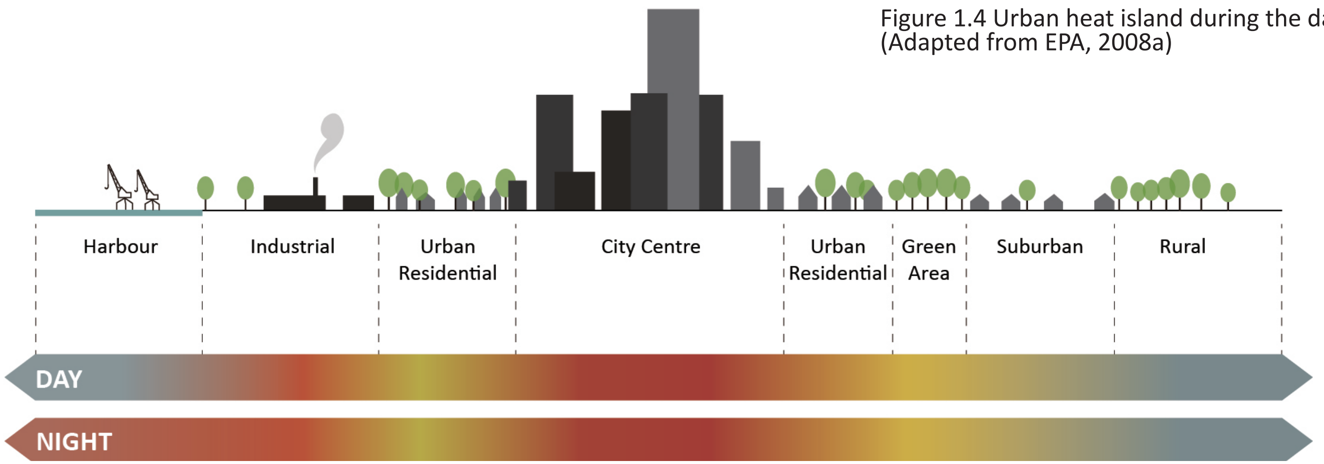
### *1.2.1 Heat stress in port cities*

Global warming refers to the rise in average surface temperature on earth, which is the most pressing issues related to recent climate change. The warming effect emerged in urban areas vary according to land use and built form, which is a hazard to city dwellers' daily life. As Monsalves-Gavilan et al. (2013) described climate change as *"a global phenomenon with local consequences"*.

Cities suffer from higher temperature in densely developed urban areas due to large impervious surface covers in the form of roofing and paving and intensive human activities (Rizwan et al., 2008). For instance, the temperature differences between urban areas such as the city centre and industrial harbour sites and the non-urbanized surroundings can be as much as 12°C (EPA, 2008a; Eliasson, 2000), especially under calm (wind) and clear (sky) weather conditions at night time. This phenomenon is commonly known as urban heat island (UHI) (Figure 1.4).

Solar radiation and anthropogenic heat are the main causes of urban heat island, both heat the city up directly and indirectly. Solar radiation relates to short-wave radiation from direct sunlight that contributes to environmental warming. In the meanwhile the urban surfaces such as building and street materials with different thermal properties absorb the heat during the day and release it back to the atmosphere at night, so-called long-wave radiation which refers to thermal storage (EPA, 2008a; Rizwan et al., 2008).

Figure 1.4 Urban heat island during the day and night (Adapted from EPA, 2008a)



Anthropogenic heat sources are the heat generated by human activities such as transportation, energy consumption by using heating or cooling facilities, and industries (Kleerekoper et al., 2012; Rizwan et al., 2008). These activities are closely related to urbanization and socio-economic development that plays a significant role in intensifying of urban heat island (Grimmond, 2011; Hurk et al., 2006) (Figure 1.5).

In consequence, the city centre is usually reported has the highest surface temperature as well as the industrial harbour sites tends to have higher temperature than the other urban locations (Rinner & Hussain, 2011; Rizwan et al., 2008). For instance, the results from a German study revealed that anthropogenic heat emitted from highly industrialized and populated Ruhr region has a permanent warming effect on the air over land areas ranging from 0.15°C up to 0.5°C (Block et al., 2004; cited by Kleerekoper, L., 2011). Also, a study conducted in the city of Chicago concluded that industrial areas are vulnerable to heat stress due to it has the highest percentages of roofed surfaces and relatively dense pavement layers, yet the lowest vegetative land covers (Gray et al., 1999).

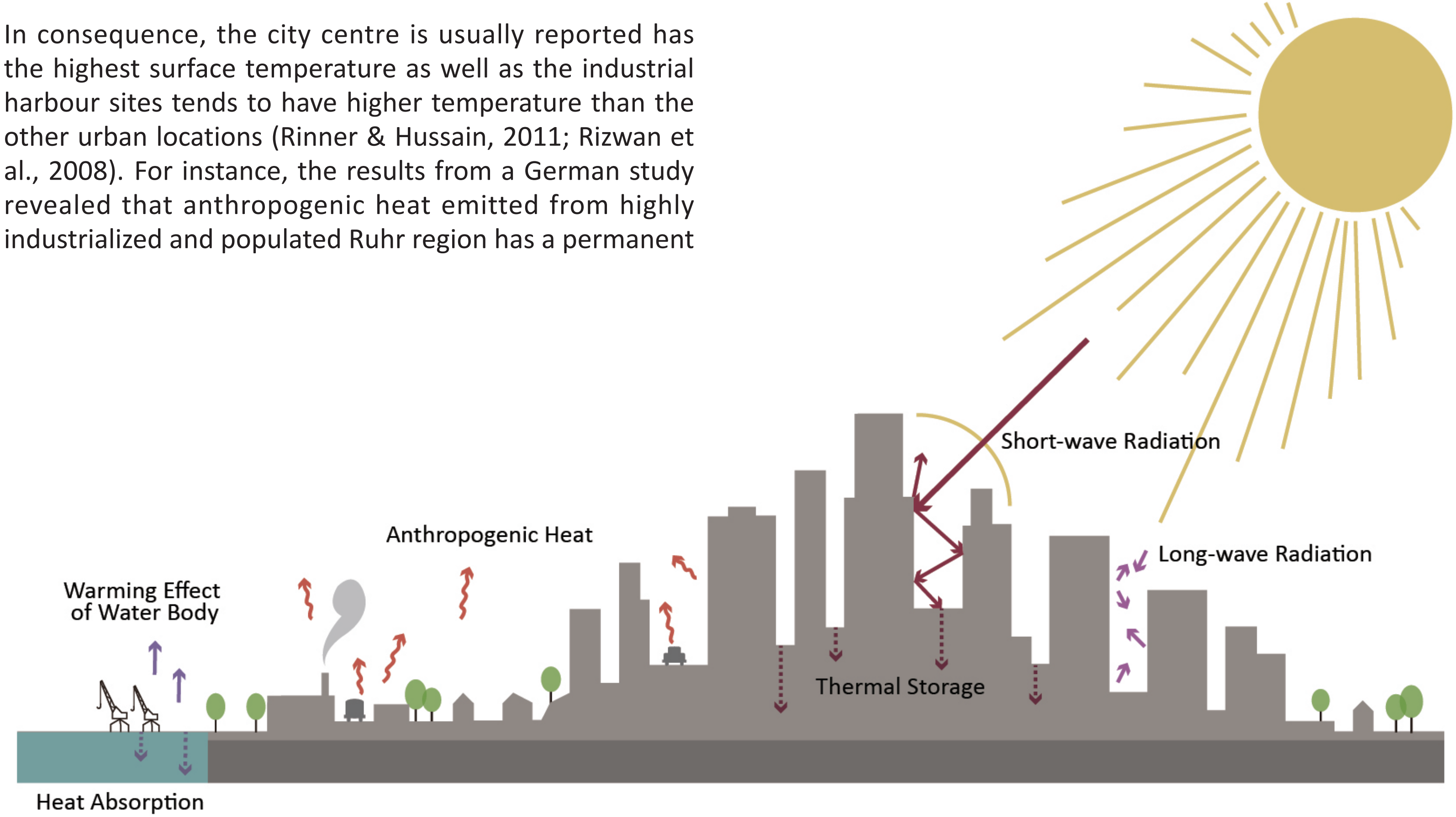



Figure 1.5 Heat sources and reflections inside urban canyons that cause urban heat island (Adapted from EPA, 2008a)

### *1.2.2 Urban heat island in the Netherlands*

The phenomenon of urban heat island (UHI) was less noticeable in Dutch cities during the past decades for the reason that the Netherlands is located in temperate zone with a mild oceanic climate (Cfb climates according to Köppen classification), and thus the impact of summertime heat islands was presumed to be minor (Steeneveld et al., 2011; Hove et al., 2011a). However, until the heat wave during the summer of 2003 hits the Netherlands have caused between 1,400 and 2,200 heat-related deaths, and then in 2006 there are two heat waves that led to an excess mortality as compared to the average mortality rate of the year without having a heat wave (Hove et al., 2011a; RCI, 2010; Garssen et al., 2005). Besides, the latest summer heat wave occurred in 2013 (DutchNews.nl, 2013ab). The emergence of extreme weather events reveals the fact that the Dutch cities are also affected by urban heat island effects as many other cities around the world (Figure 1.6).

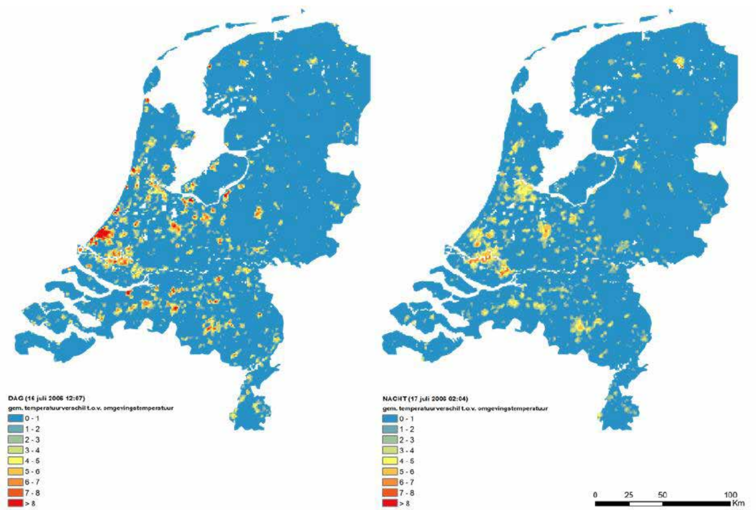


Figure 1.6 Surface heat island (SHI) effect in Dutch cities during the (left) day and (right) night (Klok et al., 2012)

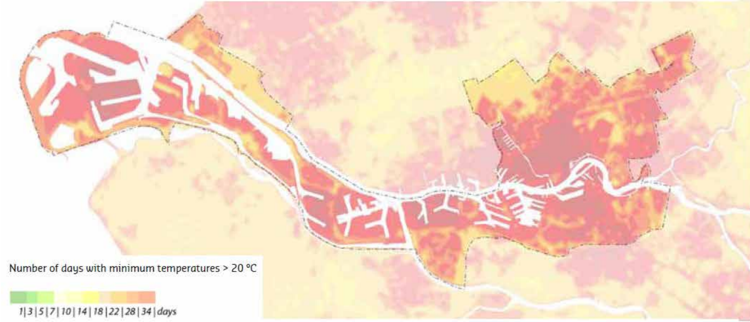



Figure 1.7 Urban heat island effect in 2050 based on the climate scenario (Source: Interactive climate atlas; cited by Gemeente Rotterdam & RCI., 2013)

According to the climate scenario reported by Royal Netherlands Meteorological Institute (KNMI) projected an increasing frequency of the number of summer days (warmer than 20°C) and tropical days (hotter than 30°C) in Dutch cities. Warm periods will occur more often and last longer in the next decades (Hurk et al., 2006) (Figure 1.7).

### *1.2.3 Human thermal comfort*

Thermal comfort is defined by the American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) and in British Standard BS EN ISO 7730 as "that condition of mind which expresses satisfaction with the thermal environment" (Shaharon & Jalaludin, 2012). There is a strong correlation between human thermal comfort and people's behaviour in response to the usability and attractiveness of outdoor places. However, the significance of psychological aspects of outdoor thermal comfort is often underestimate. Only recent studies on thermal comfort were focused more on mental aspects and have demonstrated that physical and psychological factors are both important to determine people's thermal perception (Lenzholzer & Koh, 2010; Katzschner, 2004).

On the one hand, people exposed to excessive heat can cause physical illnesses such as rashes, heat convulsions, exhaustion and heat strokes that disturb people's sleep and quality of everyday life. This lead to a higher mortality rate than the average data, especially among the elderly. For example, in the Netherlands, the number of deaths raises with 12% during heat waves (Nijhuis et al., 2011). On the other hand, the unpleasant bioclimatic conditions have adverse effects on individual's mental state and then influence their outdoor activities in terms of attendance and behaviour. For instance, people tend to feel less desirable to spend their time outside when the weather is uncomfortably warm. This could bring urban health issues and have an impact on the use of urban public spaces. Accordingly, the overuse of air-conditioning for cooling inside the buildings will intensify outdoor heat stress.

The perception of bioclimatic comfort is factually more relevant to people than the elevated temperature from urban heat islands alone (Budd, 2001, 2008; cited by Steeneveld et al., 2011; Matzarakis & Amelung 2008). This is because the thermal comfort is how people experience the weather conditions in reality and it directly reflects people's behavioural reactions to the environment. Therefore, thermal comfort is considered as one of the most influential factors in governing people's environmental satisfaction (Shaharon & Jalaludin, 2012).

#### *1.2.4 Attractiveness of living and working environment in harbour areas*

Attractiveness of cities refers to aesthetic appreciation and the quality which arouse interest in terms of social, economic and environmental aspects. Attractiveness is fundamental to design the harbour areas and to create high quality living and working environments that supports comfortable urban climate and multifunctional activities which helps people to develop a healthy lifestyle. Also, an attractive harbour area provides ample opportunities for local inhabitants and workers as well as for business investors in socio-economic terms.

A successful harbour development should be functional and aesthetically pleasing in order to attract more people for stimulating local growth. However, it is noticeable that people are likely to have negative impressions on harbour areas due to the large port-industrial complex with a general lack of vegetation and spaces for outdoor activities, and possibly the uncomfortable thermal environment and pollutions caused by intensive port activities (Rizwan et al., 2008). As a result, the quality and attractiveness of harbour areas are usually hidden and being ignored by people. From an urban planner's perspective, urban waterfront is considered as a key element with huge potential to develop the port cities and greatly adds to the charm of the harbour areas (Daamen & Vries, 2012; Kotval & Mullin, 2010; Merckx et al., 2003).

To sum up, this research attempts to tackle the heat-related problems by improving human thermal comfort and enhance the attractiveness of outdoor spaces with respect to people's environmental enjoyment, aesthetic appreciation and local identity in harbour areas.

## 1.3 Research Framework

Setting up a research framework helps to approach the research subject and to develop the research in a clear sequence. First of all, the knowledge gap is identified, and then a research objective and relevant research questions are formulated in order to bridge the knowledge gap.

### *1.3.1 Knowledge gap identification*

A review of research on the role of urban vegetation in improving thermal comfort and contributing to human health revealed several knowledge gaps. Vegetation is extensively approved that has the positive effects on thermal conditions within the city and human well-being through a large number of studies (Bowler et al., 2010; Clark et al., 2010; Tzoulas et al., 2007); also, vegetation is considered as the most promising instrument for urban microclimate improvement in physical as well as in psychological terms (Klemm et al., 2015ab; Gill et al., 2007; Smardon, 1988). However, the practical guidelines for street greenery planning and design relating to people's perceived thermal comfort are still lacking.

Most studies investigated the effects of specific green elements individually in at least one of the following categories: (1) ground vegetation; (2) wall or roof vegetation; (3) trees; (4) parks or green areas (Bowler et al., 2010). Among the four categories, parks and green areas are usually a mixture of ground vegetation and trees, which means the green elements are not being specified and compared the relative significance before putting together to create a green space. These studies were generally focused on the amount of greenery with the combination of different types of green elements (Klemm et al., 2015b; Alexandri & Jones, 2008; Velarde et al., 2007; Maas et al., 2006). Hence, the first gap is identified as people's perception of different types of street greenery (i.e. ground vegetation, wall vegetation, trees) and its effects on perceived thermal comfort and attractiveness. The roof vegetation has been excluded since the present study focuses on people's perception while roof vegetation are at roof level and thus usually less perceivable by pedestrians.

Street canyon configuration (i.e. aspect ratio and orientation) is a key factor that influence the performance of street greenery and determine how people perceive the environment in terms of thermal comfort and attractiveness. Most studies were carried out in the city centre or residential streets (Klemm et al., 2015b; Armson, 2012) because it is frequently used and represent the most common street type. However, for the harbour development project, the streets in former harbour areas are generally wider as a result of previous development. In other words, the dimension and spatial characteristics are different from regular residential streets and thus different planning and design strategies are needed. Therefore, the second gap concerns the harbour contexts for the investigation of street greenery and its contribution to thermally comfortable and attractive streetscapes in harbour areas.

### *1.3.2 Research objective and research questions*

The objective of this research is to generate practical design guidelines for thermally comfortable and attractive streetscapes in harbour areas considering people's perception of different types of urban vegetation and street configuration in harbour contexts.

In order to fulfil the research objective, the main research question is formulated as:

**What design guidelines for thermally comfortable and attractive streetscapes in harbour areas can be generated based on people's perception of street greenery?**

For answering the main research question, it is important to first identify the different functions and spatial characteristics of the street types in harbour contexts *(sRQ1)*, and then to investigate what are the physical and psychological functions of different vegetation types that contributes to thermal comfort *(sRQ2)* and attractiveness *(sRQ3)* based on the existing body of knowledge for new knowledge generation through this study. Finally a design question is formed in relation to the application of generated design guidelines *(DQ1)*.

[sRQ1] What are the different functions and typical urban typologies applied to harbour redevelopment projects and in post-industrial urban plans?

[sRQ2] What are the contributions of different types of vegetation in urban streets to improve perceived thermal comfort conditions in different functional zones within a harbour area?

[sRQ3] What are the contributions of different types of vegetation in urban streets to enhance attractiveness of different functional zones in harbour contexts?

[DQ1] How can design guidelines be implemented on urban streets with different functions and street configuration in the Rotterdam harbour areas?

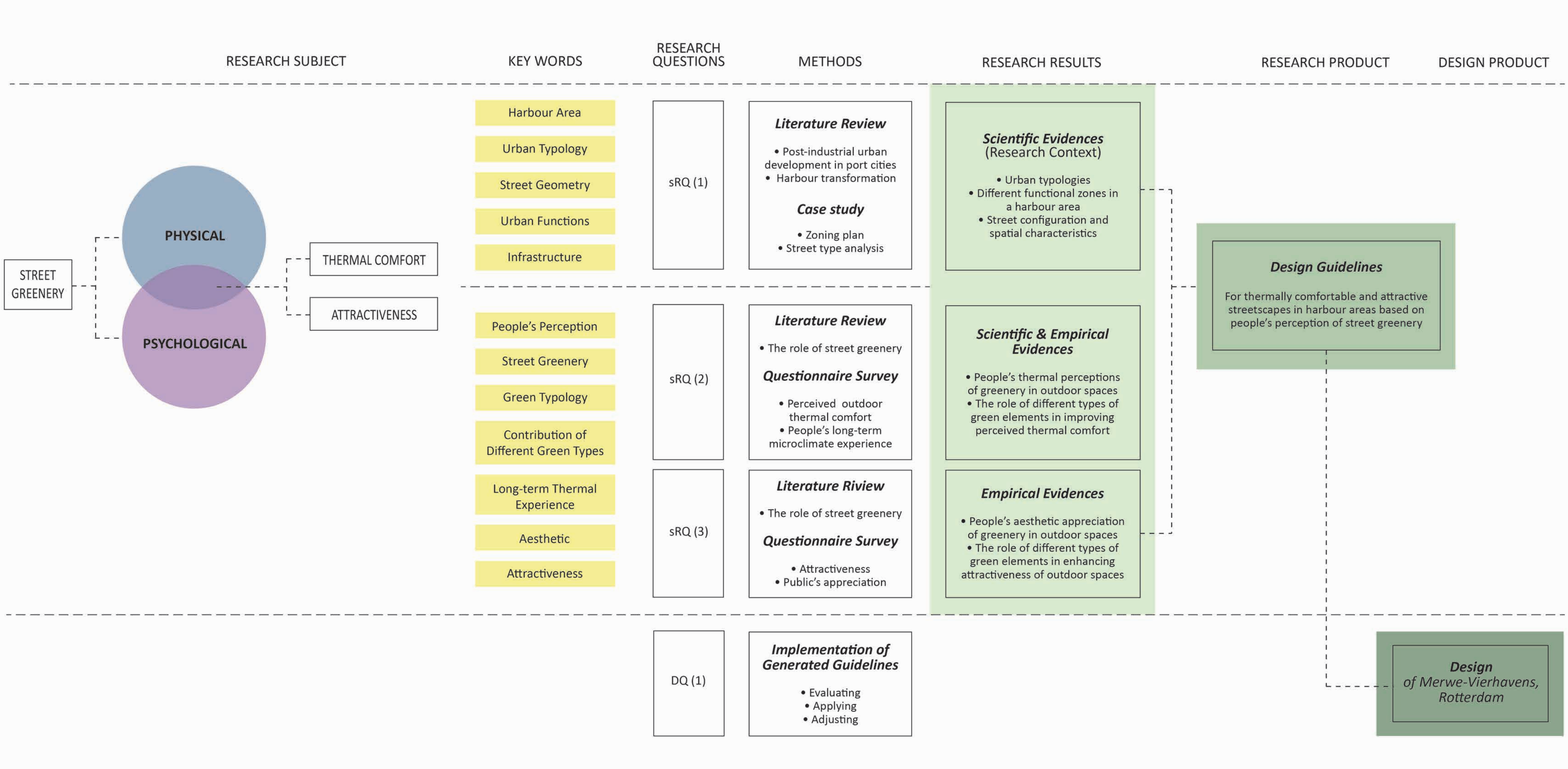



Figure 1.8 Research framework

## 1.4 Research Design

### *1.4.1 Philosophical Worldviews*

Worldview is a philosophical term that has been defined as *"a basic set of beliefs that guide action"* (Guba, 1990, p. 17; cited by Creswell, 2009). By stating the philosophical worldviews, it helps to provide a sharp theoretical lens for developing the research procedures in a good sequence with corresponding methods to conduct this study.

Overall, a pragmatic worldview was applied in the present study. Since this research is problem-focused and real-world practice oriented with a pragmatic lens. Pragmatism is strive for integrating the existing knowledge and generating applicable solutions to solve the problems (Creswell, 2009). By holding a pragmatic worldview, this study aims to develop practical design guidelines for improving thermal comfort and attractiveness of outdoor spaces in harbour areas.

Besides, the social constructivist worldview was involved specially in the process of empirical research with people-centred and experience-oriented approaches. In this study, representative sample groups were selected for investigating people's perception of different greenery types and its influences on their long-term thermal comfort and aesthetic appreciation in harbour contexts. The target participants of empirical investigation is the population of Rotterdam, as well as the possible future users of the case study area in Merwe-Vierhavens (M4H).

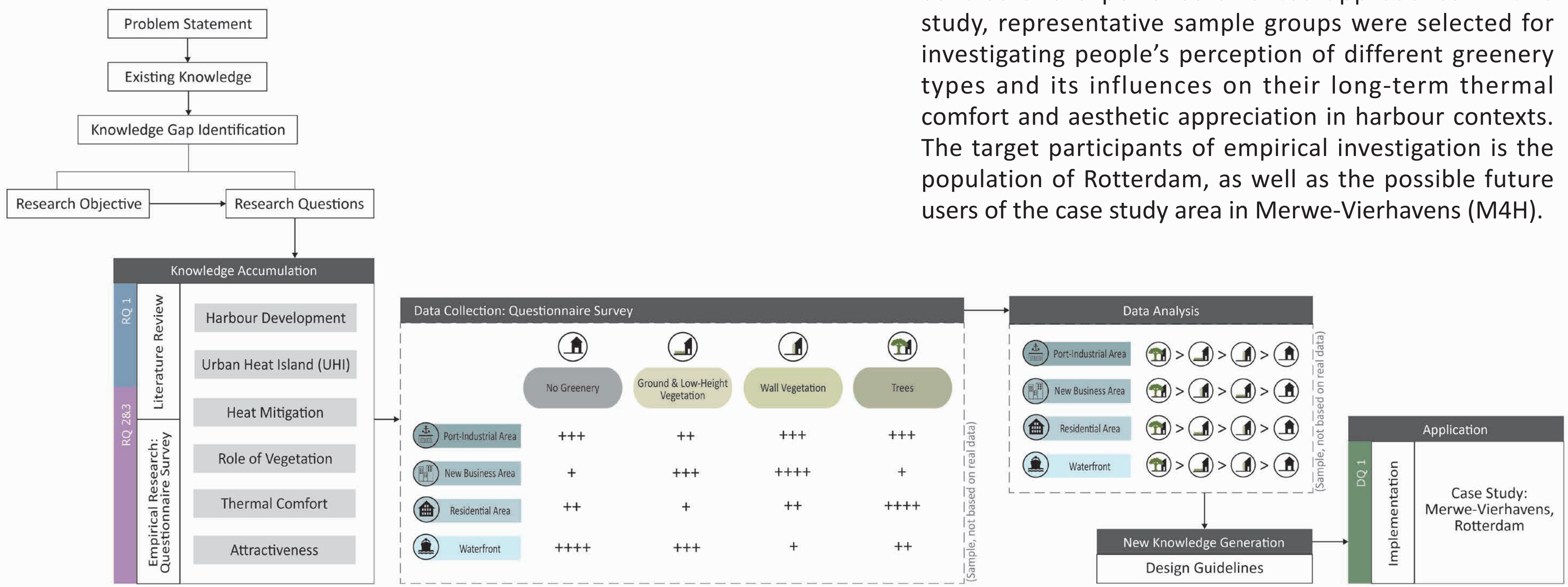



Figure 1.9 Research process flowchart

### *1.4.2 Research methods*

Overall, this research is divided into three parts.

The first part focuses on defining the most common street type with different functions and spatial characteristics in harbour contexts that has been widely applied to harbour redevelopment plans through literature review *(sRQ1)*. The second part is aim at generating new knowledge about perceived thermal comfort and aesthetic appreciation of outdoor spaces considering people's perception of street greenery by conducting empirical surveys with a visual approach in the city of Rotterdam *(sRQ2 & sRQ3)*. General design guidelines were formulated according to the research findings and combined with prior knowledge gained from literature. The last part is to put the generated design guidelines into practice and to provide practical design recommendations for developing the Merwe-Vierhavens in Rotterdam *(DQ4)*.

For each question different methods were applied in order to collect required knowledge and data and elaborated as follows:

*[sRQ1] What are the different functions and typical urban typologies applied to harbour redevelopment projects and in post-industrial urban plans?*

By reviewing the existing literature on harbour transformation, the redevelopment of former harbour sites has found a generic pattern, which 'relies on standard urban typologies build in a standard architectural language' (Diedrich, 2013). Also, the different functional zones within a harbour context can be generalised on the basis of site-specific future zoning plan developed by the local municipalities. In this case, the generalisation was made based on the transformation scenario for Merwe-Vierhavens drafted by the municipality of Rotterdam.

*[sRQ 2 & 3] What are the contributions of different types of vegetation in urban streets to improve perceived thermal comfort and attractiveness of different functional zones in harbour contexts?*

The contribution of different types of urban vegetation to perceived thermal comfort and attractiveness was investigated by means of literature review and questionnaire study in the form of online and face-to-face surveys.

For investigating people's perception of street greenery in relation to outdoor thermal comfort *(sRQ2)* and attractiveness *(sRQ3)* of urban streets, people were asked to evaluate different types of urban vegetation in harbour contexts separately during questionnaire survey (see chapter 3 for detailed explanation of the questionnaire design methods). It is clear that people's environmental perception involves multi-sensory stimulation, however, it is largely visually dominated especially in outdoor spaces (Carmona, 2010; Velarde et al., 2007). Accordingly, the questionnaire was designed in a visual approach and the visualisation was made by using Adobe Photoshop.

*[DQ1] How can design guidelines be implemented on urban streets with different functions and street configuration in the Rotterdam harbour areas?*

General design guidelines will be generated based on the results of questionnaire surveys, and practical design recommendations will be summarised into one table according to harbour functional zone with clearly defined spatial characteristics for the application in actual practice. The design guidelines will then be applied to several sample streets within Merwe-Vierhavens area which represents different functions and spatial configuration for detailed design by taking the existing situations into account.

To conclude, this study attempts to accumulate experience-based data on the effect of people's perception of different greenery types on perceived thermal comfort and attractiveness of outdoor spaces in harbour contexts by means of visual questionnaire surveys; and to link the research findings with existing body of knowledge through literature study in order to develop empirical-based and applicable design guidelines for thermally comfortable and attractive streetscapes in harbour areas.

### *1.4.3 The relationship between research and design*

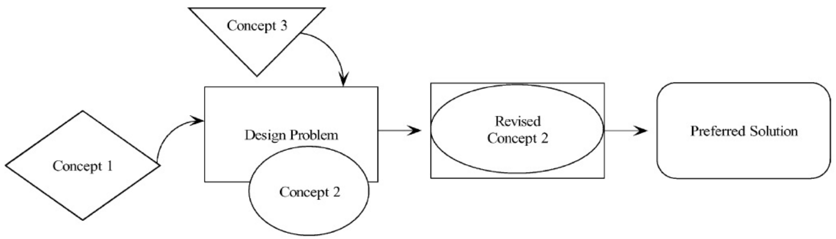
Research is regarded as an essential component of responsible planning and design process with the raising awareness of various issues such as social responsibility, human health and well-being, sustainability, and environmental responsiveness. The role of research is defined as the *"development of criteria for concept evaluation"* and *"general rules for application during design"* (Milburn et al., 2003). This is consistent with the objective of this study which is to generate design guidelines for thermally comfortable and attractive streetscapes in the harbour area by evaluating the performance of different types of street greenery.

Figure 1.10 The concept-test model: testing a series of concepts on the design problem, modifying one or more of them for finding the most suitable options and identifying a general preference as solution for the problem (Milburn et al., 2003)

The relationship between research and design in the present study is defined as *"research through designing"* (Lenzholzer et al., 2013), which research and design are closely interwoven for knowledge production.

On the one hand, the research involve design activity by developing different alternatives in the design of visualisation images used in the questionnaire in order to collect empirical data. The alternatives include the modification of general background images for the four harbour functional zones and the design of different greenery types (see chapter 3.1.1 under the subtitle of 'visual stimuli'). The process of developing the visualisation images for the questionnaire is shown in Appendix I, followed by Appendix II which shows the final version of the questionnaire with the four series of 16 visualisation images.

One the other hand, the concept-test model (Figure 1.10) was employed in developing design guidelines which strictly based on the research outcomes derived from questionnaire results to support a responsible design. Schön (1963 & 1988) proposed that *"the creation of new design concepts involves the projection of old ideas to new problems, followed by the assessment and alteration of the ideas to allow for situational differences"* (Milburn et al., 2003).



In the present study, people were asked to assess different types of street greenery within four harbour functional zones according to their long-term experience. This evaluation process tests different alternatives and generalises individual's preferences of different greenery types and its effects on perceived thermal comfort and attractiveness of streetscapes in harbour contexts. By making use of these empirical knowledge applicable design guidelines can be generated.

In short, the approach "research through designing" of this study reflect on the designing process of the visual questionnaire as well as the development of design guidelines.

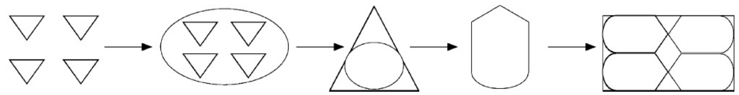


Figure 1.11 The systematic model: the research (triangular forms) determines the concept (oval), and the concept is a tool for transmitting the integrated complexities of the site (rectangle) (Milburn et al., 2003)

A systematic model (Figure 1.11) is used to express this interrelation as research play a significant role in shaping design concepts, and the design integrated the research findings to generate solutions for site-specific problem-solving. In this study, the research product will be developed in the form of design guidelines for tackling heat-related problems with relation to perceived thermal comfort and attractiveness of outdoor spaces in harbour contexts. This process can be summarised as *"problems are identified, standard solutions are applied, and the problem is resolved"* (Milburn et al., 2003); which reflects the pragmatic worldview to carry out this study.

### *1.4.4 Case study area*

Rotterdam is selected as the main study area for empirical research and Merwe-Vierhavens (M4H) is where the research outcomes will be implemented (Figure 1.12).

Rotterdam is well known for its port and as one of the largest ports in Europe, the city of Rotterdam are facing environmental challenges like many other world's major port cities due to the shifts of economic activity, urbanisation, and climate change. As a result, many harbour sites within the city are undergoing a process of transformation. The municipality has embarked on a harbour revitalisation project named 'Stadshavens Rotterdam' in collaboration with the port authority to transform several harbour sites into mixed-use urban areas and to develop a symbiotic relationship between city and port that they can flourish together.


Figure 1.12 Study area (including Schiedam and Capelle aan den Ijssel); the yellow box indicates the location of Merwe-Vierhavens area

M4H is one of the focus areas of this project and the municipality aims to create high quality living and working environments that attracts people. More information about Stadshavens project and the case study M4H area are illustrated in chapter 5.1.

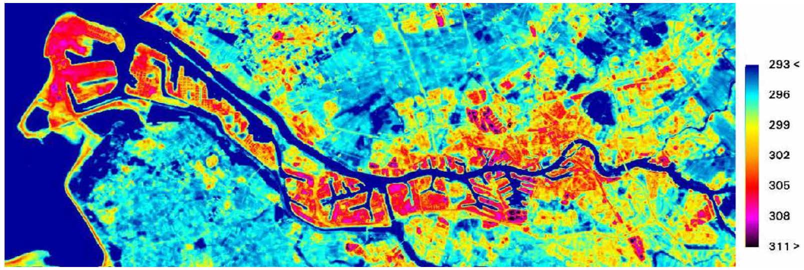



Figure 1.13 Average surface temperature in Rotterdam (Klok et al., 2009)

Rotterdam is confronting urban heat island (Figure 1.13), the temperature difference of more than 7°C were found between urban and rural areas at night (Nijhuis et al., 2011). The results of a study on UHI intensity of Dutch cities at street level reveals that most of the Dutch cities are subject to heat stress for about 7 days per year; whilst Rotterdam suffers from heat stress for about 15 days per year. This shows a higher frequency of nocturnal UHI in Rotterdam and the city is in urgent need of solutions (Heusinkveld et al., 2012; Steeneveld et al., 2011).

Regarding outdoor thermal comfort which relates to air temperature within street canyons, a measurement was carried out in the city of Rotterdam (Figure 1.14) and the results were calculated into Physiological equivalent temperature (PET) as thermal index to investigate people’s comfort conditions.

In Rotterdam, the highest PET values are occurred in parts of the city centre and the surrounding neighbourhoods, northwest industrial areas where M4H situated, and the urban area on south bank of river Nieuwe Maas (Figure 1.15) (Hove et al., 2011b).

In consequence, Rotterdam is suitable for investigating urban heat islands associated with thermal comfort and attractiveness of outdoor spaces in harbour contexts.

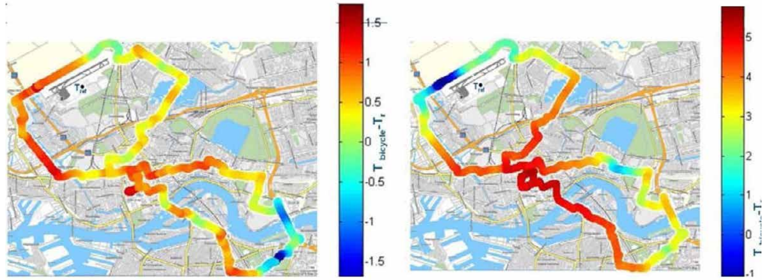


Figure 1.14 Air temperature in the urban canopy layer in Rotterdam (Hove et al., 2011b)

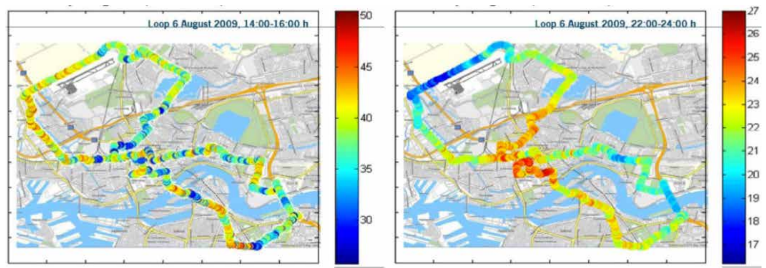



Figure 1.15 Physiological equivalent temperature (PET) in Rotterdam; calculated from the results of Figure 1.11 (Hove et al., 2011b)

### *1.4.5 Relevance and target audience*

This thesis is undertaken as part of the research study for the transformation of Merwe-Vierhavens (M4H) under the major project “Stadshavens Rotterdam” launched by the municipality of Rotterdam.

This study investigated how to create thermally comfortable and attractive streetscapes in harbour areas by using different types of street greenery. The research outcomes could be used in ongoing projects, especially for M4H area, and contributed as an example of street design for harbour redevelopment plans in Dutch context.

Furthermore, the general design guide-lines can be applied to other port cities under similar circumstances. This helps to enlarge the applicability of the research outcomes and extend the research subject. Therefore, this thesis could be interested for the municipality of Rotterdam, landscape architects, urban designers, planners and developers.

# Reference

**A** Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment, 43, 4, 480-493.

Armson, D. (2012). The effect of trees and grass on the thermal and hydrological performance of an urban area. PhD Thesis, Faculty of Life Sciences. University of Manchester.

**B** Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning, 97, 3, 147-155.

**C** Carmona, M. (2010). Public places, urban spaces: the dimensions of urban design. Routledge.

Clark, C., Busiek, B., & Adriaens, P. (2010). Quantifying thermal impacts of green infrastructure: Review and gaps. Proceedings of the Water Environment Federation, 2010, 2, 69-77.

Creswell, J. W. (2009). Research design: qualitative, quantitative and mixed methods approaches. Los Angeles, CA: SAGE Publications.

**D** Daamen, T. A., & Vries, I. (2012). Governing the European port–city interface: institutional impacts on spatial projects between city and port. Journal of Transport Geography.

Diedrich L. (2013). Translating harbourscapes: site-specific design approaches in contemporary European harbour transformation. Frederiksberg: Department of Geosciences and Natural Resource Management, University of Copenhagen.

Dimoudi, A, & Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. Energy and Buildings, 35, 69-76.

DutchNews.nl (22 July 2013a). Temperature set to hit 34 Celsius as heatwave continues. Retrieved from: http://www.dutchnews.nl/news/archives/2013/07/temperature_set_to_hit_34_cels.php

DutchNews.nl (25 July 2013b). It's official! The sweltering weather is a heatwave. Retrieved from: http://www.dutchnews.nl/news/archives/2013/07/its_official_the_sweltering_we.php

**E** Eliasson, I. (2000). The use of climate knowledge in urban planning. Landscape and Urban Planning, 48, 31-44.

EPA. (2008a). Reducing urban heat islands: compendium of strategies: urban heat island basics. Washington, DC: Climate Protection Partnership Division, U.S. Environmental Protection Agency.

**G** Garssen, J., Harmsen, C., De Beer, J. (2005). The effect of the summer 2003 heat wave on mortality in the Netherlands. Euro Surveill, Eurosurveillance report, 10, 7, 165-8. Available at: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=557

Gemeente Rotterdam & RCI. (2013). Rotterdam climate change adaptation strategy. Available at: http://www.turas-cities.org/uploads/biblio/document/file/271/RCI_RAS_2013_EN_LR.pdf [Accessed at: 30-01-2014]

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: the role of the green infrastructure. Built Environment (33):1, 115-133.

Gray, K. A., Finster, M. E., United States Environmental Protection Agency (EPA), & Northwestern University (1999). The urban heat island, photochemical smog, and Chicago: Local features of the problem and solution. Evanston, IL: Northwestern University, Dept. of Civil Engineering.

Grimmond, S. (2011). London's urban climate: historical and contemporary perspectives. In: Hebbert, M., Jankovic, V., Webb, B., & University of Manchester (Eds.) (2011). City weathers: meteorology and urban design 1950-2010. Manchester Architecture Research Centre (MARC) 61-74.

**H** Heusinkveld, B. G., Steeneveld, G. J., L. W. A. van Hove, Jacobs, C. M. J., & Holtslag, A. A. M. (2012) Spatial variability of the Rotterdam urban heat island as influenced

by urban land use. J. Geophys. Res. Atmos., 119, 677-692, doi: 10.1002/ 2012JD019399.
Hove, B. van, Jacobs, C. M. J., Heusinkveld, B. G., Elbers, J. A., Steeneveld, G. J., Moors, E.J., & Holtslag, A. A. M. (2011b). Exploring the urban heat island intensity of Dutch cities. In: Hebbert, M., Jankovic, V., Webb, B., & University of Manchester (Eds.) (2011). City weathers: Meteorology and urban design 1950-2010. Manchester Architecture Research Centre (MARC), 31-38.
Hove, B. van, Steeneveld, G. J., Jacobs, C. M. J., Maat, H.W. ter, Heusinkveld, B. G., Moors, E.J., & Holtslag, A. A. M. (2011a). Modelling and observing urban climate in the Netherlands. Wageningen: Alterra, 2010. KvR report number: KvR 020/11.
Hurk, B., Tank, A. K., Lenderink, G., Ulden, A., Oldenborgh, G. J., Katsman, C., Brink, H., Keller, F., Bessembinder, J., Bugers, G., Komen, G., Hazeleger, W., & Drijfhout, S. (2006). KNMI climate change scenarios 2006 for the Netherlands. KNMI Scientific Report WR 2006-01. De Bilt: KNMI.

**K** Katzschner, L. (2004). Open space design strategies based on thermal comfort analysis. Proceedings of International PLEA Conference 2004, Vol. 1, 47-52.
Kleerekoper, L. (2011). Heat mitigation in Dutch cities by the design of two case studies. Delft University of Technology. 5th AESOP Young Academics Network Meeting, Resilience Thinking and Climate Change. 2011, the Netherlands.
Kleerekoper, L., van, E. M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. Resources, Conservation & Recycling, 64, 30-38.
Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015b). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning.
Klemm, W., Heusinkveld, B. G., Lenzholzer, S., Jacobs, M. H., & Van, H. B. (2015a). Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment, 83, 120-128.
Klok, E.J., Schaminée, S., Duyzer, J., & Steeneveld, G.J. (2012). De stedelijke hitte-eilanden van Nederland in kaart gebracht met satellietbeelden. Earth, Environmental and Life Sciences. TNO-rapport, TNO-060-UT-2012-01117.
Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2009). The surface heat island of Rotterdam derived from satellite imagery. SENSE Symposium Climate Proofing Cities, Amsterdam & Volendam, 1 December 2009.
Kotval, Z., & Mullin, J. (2010). The changing port city: sustainable waterfront revitalization. Henry Stewart Publications 1756-9538. Journal of Town & City Management (1):1, 23-38.

**L** Lafortezza, R., Carrus, G., Sanesi, G., & Davies, C. (2009). Benefits and well-being perceived by people visiting green spaces in periods of heat stress. Urban Forestry & Urban Greening, 8, 2, 97-108.
Lenzholzer, S., & Koh, J. (2010). Immersed in microclimatic space: Microclimate experience and perception of spatial configurations in Dutch squares. Landscape and Urban Planning, 95, 1-15.
Lenzholzer, S., Duchhart, I., & Koh, J. (2013). 'Research through designing' in landscape architecture. Landscape and Urban Planning, 113, 120-127.

**M** Maas, J., Verheij, R.A., Groenewegen, P.P., Vries, S., de, & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation? Epidemiology and Community Health, 60, 587-592.
Madanipour, A., Knierbein, S., & Degros, A. (2014). Public space and the challenges of urban transformation in Europe. New York, N.Y: Routledge.
Matzarakis, A., & Amelung, B. (2008). Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans. In: Thomson, M. C., García, H. R., & Beniston, M. (Eds.) (2008). Seasonal forecasts, climatic change and human health: Health and climate. Dordrecht: Springer. Chapter 9: 161-172.

Merckx, F., Notteboom, T., & Winkelmans W. (2003). Spatial models of waterfront redevelopment: the tension between city and port revisited. Proceedings of Annual IAME Conference 2003, Busan, South-Korea. 267-285.

Milburn, Lee-Anne S., & Brown, Robert D. (2003). The relationship between research and design in landscape architecture. Landscape and Urban Planning, 64, 47-66.

Monsalves-Gavilan, P., Pincheira-Ulbrich, J., & Rojo, M. F. (2013). Climate change and its effects on urban spaces in Chile: a summary of research carried out in the period 2000-2012. Atmosfera, 26, 4, 547-566.

Moonen, P., Defraeye, T., Dorer, V., Blocken, B., & Carmeliet, J. (2012). Urban physics: effect of the micro-climate on comfort, health and energy demand. Frontiers of Architectural Research, 1, 3, 197-228.

**N**

Nijhuis, E. W. J. T., Gemeentewerken Rotterdam., & TNO. (2011). Hittestress in Rotterdam: eindrapport. Utrecht: Kennis voor Klimaat. Projectcode: HSRR05. Available at: http://www.kennisvoorklimaat.nl/HSRR05 [Accessed at: 27-02-2014]

Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: analysis across different European countries. Building and Environment, 41, 11, 1455-1470.

**Q**

Qin, J., Zhou, X., Sun, C., Leng, H., & Lian, Z. (2013). Influence of green spaces on environmental satisfaction and physiological status of urban residents. Urban Forestry and Urban Greening, 12, 4, 490-497.

**R**

Rinner, C., & Hussain, M. (2011). Toronto’s urban heat island— exploring the relationship between land use and surface temperature. Remote Sensing (3):12, 1251-1265.

Rizwan, A., Dennis, L., & Liu, C. (2008). A review on the generation, determination and mitigation of urban heat island. Journal of Environmental Sciences (20):1, 120-128.

Rotterdam Climate Initiative (RCI.) (2010). Rotterdam's climate adaptation: research summaries 2010. Available at: http://www.rotterdamclimateinitiative.nl/documents/RCP/English/RCI_cahier_300_def.pdf [Accessed at: 03-04-2014]

**S**

Shaharon, M. N., & Jalaludin, J. (2012). Thermal comfort assessment-a study toward workers' satisfaction in a low energy office building. American Journal of Applied Sciences, 9, 7, 1037-1045.

Shashua-Bar, L., & Hoffman, M. E. (2000). Vegetation as a climatic component in the design of an urban street. Energy and Buildings, 31, 3, 221-235.

Smardon, R. C. (1988). Perception and aesthetics of the urban environment: review of the role of vegetation. Landscape and Urban Planning, 15, 85-106.

Steeneveld, G. J., Koopmans, S., Heusinkveld, B. G., L. W. A. van Hove, & Holtslag, A. A. M. (2011). Quantifying urban heat island effects and human comfort for cities of variable size and urban morphology in the Netherlands. J. Geophys. Res., 116, D20129, doi: 10.1029/ 2011JD015988.

**T**

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning, 81, 3, 167-178.

**U**

Ulrich, R. S. (1986). Human responses to vegetation and landscapes. Landscape and urban planning, 13, 29-44.

United Nations (2014). Department of Economic and Social Affairs, Population Division. World urbanization prospects: the 2014 Revision, highlights (ST/ESA/SER.A/352).

**V**

Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes - Landscape types in environmental psychology. Urban Forestry & Urban Greening, 6, 4, 199-212.

**W**

World Bank (2010). Cities and climate change: an urgent agenda. Washington, D.C: The International Bank for Reconstruction and Development/ The World Bank.

Photo credit: Christy Tang. (2012).

# 2 Theoretical Background

**Overview**

This chapter demonstrates the essential knowledge required to answer the research questions.
First, the development of harbour areas in the port city is fundamental to understand the contexts and to observe the generic formula for harbour redevelopment. Second, it is important to explore urban heat island and thermal comfort in order to define study scale, to improve thermal environments and deal with heat-related problems. Third, the thermal benefits and aesthetic values of urban vegetation were specified according to greenery type. In this way, it helps in understanding the physical functions and psychological effects of urban vegetation. Last but not least, the effects of urban built environment on the performance of vegetation in improving thermal comfort within street canyons is closely related to the development of practical design guidelines.

The prior knowledge and scientific evidences are necessary to support the research and to be integrated with the collected data through this study for developing reliable and responsible design guidelines (new knowledge generation).

## 2.1 The Concept of Urban Waterfront Regeneration and Harbour Redevelopment

### *2.1.1 Port-city interface*

Port-city interface is defined as *"waterfront zones in which the geography of the port and its city meet each other"* (Daamen & Vries, 2012). Traditionally, many ports were located within the urban area due to economic activities. In consequence, the relationship between port and city has been closely tied to one another geographically and functionally. According to Hayuth (1982), the port-city interface is shaped by spatial system and ecological system. The former reflects land-use structures and functional linkages; the latter is concerned with environmental qualities and aesthetic values. And both systems have a correlation with economic system at the core of port city activities (Hoyle, 1989; Hayuth, 1982). As a result, urban waterfront have been used as vehicles for attracting new investments and facilitating the harbour redevelopment and post-industrial urban plans.

Today, many spaces left vacant by abandoned warehouses and disused harbour operations have been turned into housing and non-port related uses such as cultural and recreational investments, which provides ample opportunities for creating attractive living and working environment. However, that is not to say that all the port activities will be replaced by urban functions, the integration of port and urban functions that reinforce each other is more significant for long-term development.

| STAGE | SYMBOL ○ city ● port | PERIOD | CHARACTERISTICS |
|---|---|---|---|
| I Primitive port/city | | Ancient/medieval to 19th century | Close spatial and functional association between city and port |
| II Expanding port/city | | 19th-early 20th century | Rapid commercial/industrial growth forces port to develop beyond city confines, with linear quays and break-bulk industries |
| III Modern industrial port/city | | mid-20th century | Industrial growth (especially oil refining) and introduction of containers/ro-ro require separation/space. |
| IV Retreat from the waterfront | | 1960s-1980s | Changes in maritime technology induce growth of separate maritime industrial development areas |
| V Redevelopment of the waterfront | | 1970s-1990s | Large-scale modern port consumes large areas of land/water space, urban renewal of original core |

Table 2.1 The evolution of the port-city interface (Hoyle, 1989)

According to Hoyle (1989), the development of urban waterfront is not only depends on technology and economic trends but also on public awareness of environmental issues. He summarised stages in the evolution of the port-city interface in chronological sequences (Table 2.1), which is in parallel with Toffler's (1980) three waves of port-city development, namely *"value-added labour"*, *"value-added production"*, and *"value-added service"* (Huang et al., 2011). With all these processes lead to the current stage of waterfront regeneration and harbour redevelopment.

### 2.1.2 Common development orientations

*"The port-city interface has taken the form of an active urban expansion over the port area"* (Malezieux, 1997; cited by Bazan-Lopes, 2001), which means the city is expanding towards the waterfront at a lively pace in order to relieve the pressure on urban population growth and the demand of quality outdoor spaces for public life; while the development of port is relatively slowing down due to the retreat of port activities and the economic restructure (Wiegmans & Louw, 2011; Merckx et al., 2003).

It has been observed that the redevelopment of harbour areas seems nearly the same in port cities around the world both programmatically and formally, regardless of the huge differences in geographical, social and historical backgrounds. Therefore, the common development orientations of transforming the former harbour areas into mixed-use urban area were generalised and described as *"the global problem of harbour transformation has generated a global solution"* (Diedrich, 2013).
Common development orientations refers to the widely accepted models of development derived from the knowledge shared in particular context. The derelict spaces are often developed and built with generic patterns so that the models can be adapted to diverse contexts and applied to different cities (Diedrich, 2013; Daamen & Vries, 2012; Merckx et al., 2003).

These standard development projects are usually in a mixture of new and old based on the existing urban fabric and associated with the functional adaptation of former harbour areas.

This process frequently involves the newly built constructions such as new houses, office complexes, shops, parks, cultural and leisure facilities (Figure 2.1); and the historical buildings and harbour elements such as warehouses, a preserved old crane, a smokestack, and a historic façade (Figure 2.2) (Diedrich, 2013; Wiegmans & Louw, 2011; Włodarczyk, 2011; Huang et al., 2011; Merckx et al., 2003; Bazan-Lopes, 2001).


Figure 2.1 The new architecture for business, commercial, residential and cultural etc. non-port related functions (Diedrich, 2013)

Moreover, Bazan-Lopes (2001) depicted the different functions as potential and applicable alternatives for the urban waterfront and harbour development, which are cultural activities (e.g. thematic parks, sailing ports, artistic markets, university buildings), public spaces (e.g. promenades, parks), specific productive sites (e.g. technological and science parks), high-specialised services (e.g. media locations, multinational centres) and mixed-income residences.


Figure 2.2 The preservation of historic buildings and harbour elements adapted for the new urban functions (Diedrich, 2013)

To sum up, the land-use structures has changed and the traditional port functions such as transportation, storage, loading and unloading has largely taken over by post-industrial, business, commercial, residential, environmental, administrative and logistic services in harbour redevelopment process in order to link diversified activities and specialised services within the harbour areas that supports a better living conditions (Bazan-Lopes, 2001). The integration between non-port related functions and maritime services and port-based economic activities is considered as the most likely outcome for harbour redevelopment.

## 2.2 Urban Heat Island and Thermal Comfort

### *2.2.1 Scales and types of urban heat islands*

Oke (1976) has clarified the distinction between urban canopy layer and urban boundary layer according to the different levels of atmosphere for urban heat island studies. The urban canopy layer (UCL) is the atmospheric layer that extends from ground level to approximately the mean building height; whilst the urban boundary (UBL) layer is *"from the top of the UCL to an altitude when urban influences are no longer felt in the atmosphere"* (Bridgman et al., 1995; cited by Gill et al., 2004).

It would be inappropriate to use the measurements made in boundary layer for investigating the canopy layer urban heat island, due to the canopy climate is largely determined by the site-specific characteristics such as street geometry, building materials and vegetation covers instead of by the boundary-layer mechanisms (Oke, 1976).

Hence, Oke (1976) proposed that there are three different scales of urban heat island studies, that is, mesoscale, local scale, and microscale (Figure 2.3). The numbers in brackets refer to the characteristic dimensions of approximate limits suggested by Oke.

*- Microscale or street canyon scale (1cm-1km)*
Referring to the climate of urban canopy layer that associates with individual buildings, trees, roads, streets, and the spaces in-between such as courtyards, gardens etc. Which is the typical scale for the investigation of urban microclimates.

*- Local scale or neighbourhood scale (100m-50km)*
Focusing on the urban boundary layer climate of neighbourhoods with similar combinations of urban features such as surface cover, size and spacing buildings, activity. This scale includes landscape features such as topography but excludes microscale effects.

*- Mesoscale or city scale (10km-200km)*
Referring to the climate of urban boundary layer that cities can play a role in influencing the climate on larger scale. The city elements in the microscale are affected by phenomena at the local scale; conversely, the phenomena at the local scale or neighbourhood scale are affected by the conditions and interactions of the mesoscale.
(Harris & Coutts, 2011; Hove et al., 2011b; Oke, 1976)

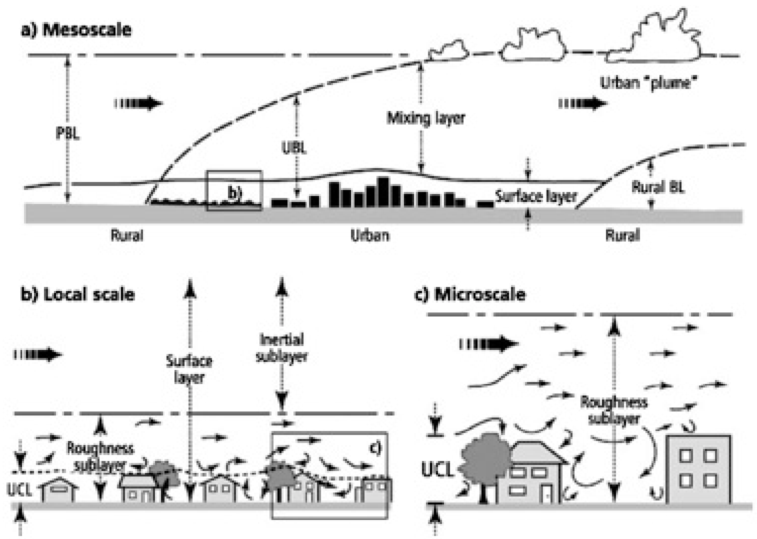



Figure 2.3 The different scales of urban heat islands; UBL is the urban boundary layer, and UCL is the urban canopy layer (Oke, 2009; cited by Harris & Coutts, 2011)

Based on the different scale levels, four types of urban heat islands were classified as follows:

*- Subsurface urban heat island (sSUHI)*
Referring to the stored heat under the city that results from the thermal conduction through surface soils and materials, and the soil temperature was determined down to 2 metres below the ground level.
The interaction between radiative energy and ground, the thermal properties and conductivities of particular surfaces to absorb, reflect or emit energy fluxes are responsible for the subsurface urban heat island variability. Besides, sSUHI is likely to affect the underground infrastructure such as water pipes etc.

*- Surface urban heat island (SUHI)*
Referring to a phenomenon that typically presents day and night, when the temperature of urban surfaces is higher than the surrounding rural (natural) surfaces. The SUHI is closely related to the direct sun light, and thus the effects are generally largest during the day when the sun is shining and the sky is clear with little wind while are relatively weaker at night.

*- Canopy layer urban heat island (CLUHI)*
Focusing on the air temperature within the street canyons that the boundary is drawn between the ground and just below the roof level. The CLUHI is commonly observed at night under a stable weather conditions due to the impacts of sSUHI that the stored heat under the urban surfaces are released back to the atmosphere.

*- Boundary layer urban heat island (BLUHI)*
Referring to the combinations of local influences in boundary layer that forms a dome of warmer air extending downwind of the city. *"It may be one kilometre or more in thickness by day, shrinking to hundreds of metres or less at night"*. Clearly, the BLUHI is also most pronounced at night time.
(Harris & Coutts, 2011; Erell et al., 2011; Hove et al., 2011b)

It is clear that there is a significant correlation between different scales and types of urban heat islands.
Overall, sSUHI and SUHI are generally described as surface urban heat island while CLUHI and BLUHI are defined as atmospheric urban heat island. The distinction between these two types of urban heat islands is necessary to be made, because they differ in many aspects such as the formation, the techniques used to identify and measure the situations, the impacts, and to a certain extent, the available methods of mitigation; which can lead to totally different directions of the research outcomes (Table 2.2) (Pötz et al., 2012; Hove et al., 2011b; EPA, 2008a). Consequently, it is fundamental to identify an appropriate study scale for the corresponding research subjects.

In the present study, a **microscale or street canyon scale** was adopted to investigate canopy layer urban heat island (CLUHI), which is most relevant to perceived outdoor thermal comfort at street level.

Table 2.2 The distinction of characteristics between surface and atmospheric urban heat islands (EPA, 2008a)

| Feature | Surface UHI | Atmospheric UHI |
|---|---|---|
| **Temporal Development** | • Present at all times of the day and night<br>• Most intense during the day and in the summer | • May be small or non-existent during the day<br>• Most intense at night or predawn and in the winter |
| **Peak Intensity (Most intense UHI conditions)** | • More spatial and temporal variation:<br>▪ Day: 18 to 27°F (10 to 15°C)<br>▪ Night: 9 to 18°F (5 to 10°C) | • Less variation:<br>▪ Day: -1.8 to 5.4°F (-1 to 3°C)<br>▪ Night: 12.6 to 21.6°F (7 to 12°C) |
| **Typical Identification Method** | • Indirect measurement:<br>▪ Remote sensing | • Direct measurement:<br>▪ Fixed weather stations<br>▪ Mobile traverses |
| **Typical Depiction** | • Thermal image | • Isotherm map<br>• Temperature graph |

### 2.2.2 *Outdoor thermal comfort*

People's perceived thermal comfort is closely linked to the usability in terms of outdoor activities and aesthetic appreciation of urban spaces. Therefore, understanding and evaluating thermal comfort conditions is essential to develop the urban environment.

To investigate outdoor thermal comfort, the microclimatic components wind, humidity, radiation, and air temperature are the main factors which affects people's thermal comfort. In addition, it is necessary to take into account not only physical and physiological parameters but also individual (gender and age), behavioural (e.g. clothing and level of activity) and psychological aspects (long- and short-term experiences, thermal expectations, time of exposure, environmental stimulation and perceived control). (Klemm et al., 2015b; Chen & Ng, 2012; Matzarakis & Amelung 2008; Gaitani et al., 2007; Nikolopoulou & Steemers, 2003; Santamouris et al., 2000) The former physical and physiological parameters provide *"climatic knowledge"*, and the latter individual, behavioural and psychological aspects provide *"human knowledge"* for assessing and investigating perceived outdoor thermal comfort (Chen & Ng, 2012).

Hanna (1996) has summarised three main approaches in dealing with the relationship between the human beings and their thermal environment.
Firstly, the physical approach generally refers to laboratory-based studies, which aims to establish bio-meteorological comfort indices applying mathematical heat balance equations.

The most well-known findings is Fanger's predicted mean vote (PMV) and predicted percentage dissatisfied(PPD). By using a seven-point thermal sensation scale (-3 to +3) the PMV can be calculated in a particular setting with a set of environmental variables, compatible with an assumed metabolic rate and clothing level. However, it is argued that this method is not applicable particularly in an outdoor environment owing to human body's ever-changing thermal state caused by the interaction between the heat flows and the human body (Figure 2.4) while the PMV equation rests on steady-state heat transfer of human body. This means that there is the possibility of error resulted from the findings lie outside the established comfort range because people adapt to their surroundings and accept conditions in a dynamic pattern.

Secondly, the biological approach aims to integrate several aspects in one relationship and develop a more holistic approach to the study on human thermal environments. For instance, the psycho-physiological model of thermal perception developed by Auliciems (1981) in order to provide practical recommendations for comfortable indoor thermal environment on the basis of three aspects: perception of warmth associated with physiological response thermal stimulus, the thermoregulatory

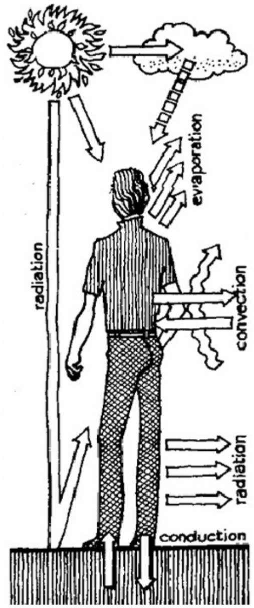



Figure 2.4 Thermal exchange between the human body and its environment. Retrieved from: http://cac.mcgill.ca/schoenauer/cases/large_image.php?slideid=181

activity in relation to subjective acceptability, and thermal sensation with respect to the levels of discomfort. However, he pointed out the inadequacy of the existing physiological models and research methods and argued that perception is *"made of higher levels of mental integration of information flows"* and *"must include parameters of past cultural and climatic experiences and expectations"* (Auliciems, 1981).

Thirdly, the psychological approach, described by Hopkinson as a *"stimulus-response relationship"* and usually based on field studies. This approach is considered as the one most useful to planners and designers, since it relates to the objective (physical environment) and the subjective (people's perception) domains of thermal comfort (Hanna, 1996).

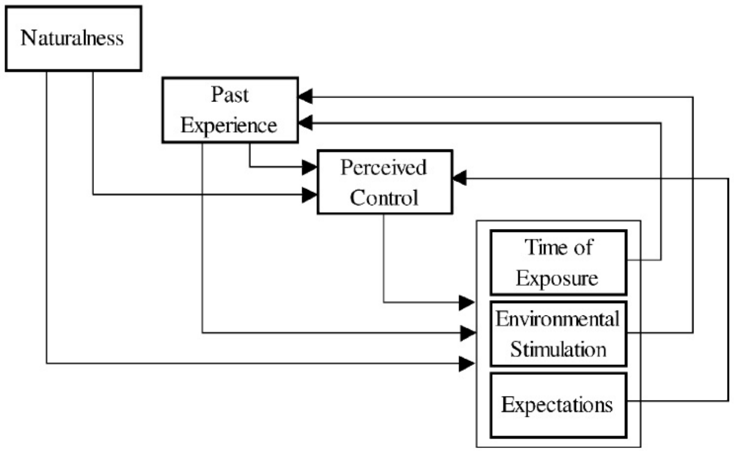



Figure 2.5 The interrelationships between the different parameters of psychological adaptation in a network (Nikolopoulou & Steemers, 2003)

Nikolopoulou & Steemers (2003) developed a network demonstrating the interrelationships among various parameters of psychological adaptation (Figure 2.5) in order to compare the relative significance of the different parameters and to identify their design role.

Physiological equivalent temperature (PET) proposed by Höppe has been extensively used to investigate outdoor thermal comfort (Table 2.3). PET is a bio-meteorological comfort index to indicate people's thermal conditions based on heat balance of the human body (Klemm et al., 2015a; Hove et al., 2011b; Deb & Ramachandraiah, 2010; Matzarakis & Amelung 2008).
It has been used for the evaluation of different thermal environments within cities, including the consequences of a changed thermal environment caused by different planning variations and strategies for improving thermal conditions. For example, taking advantage of the effect of different kinds of greenery or increasing green areas planted with trees (Erell et al., 2011).

| PET | Thermal perception | Grade of physiological stress |
|---|---|---|
| | Very cold | Extreme cold stress |
| 4°C | Cold | Strong cold stress |
| 8°C | Cool | Moderate cold stress |
| 13°C | Slightly cool | Slight cold stress |
| 18°C | Comfortable | No thermal stress |
| 23°C | Slightly warm | Slight heat stress |
| 29°C | Warm | Moderate heat stress |
| 35°C | Hot | Strong heat stress |
| 41°C | Very hot | Extreme heat stress |

Table 2.3 Ranges of physiological equivalent temperature (PET) indexes with different degrees of thermal perception by human beings (Matzarakis & Amelung 2008)

Furthermore, Katzschner (2004) used the calculations of PET thermal comfort index and linked the each of the PET value to a different levels of outdoor activity and its required thermal conditions for use of the urban spaces. The results are shown in Table 2.4.

| activities | needed thermal conditions for use of open spaces | PET °C |
|---|---|---|
| sitting | warm | 30 |
| calm activities | warm moderate | 26-32 |
| children play | warm moderate | 24-26 |
| recreation | neutral | 16-24 |
| light movement | neutral | 16-26 |
| shopping | warm moderate | 26-32 |
| movement | lightly cool | 14-24 |
| strong movement | cool to cold | 12-24 |
| garden activities | lightly cool | 12-24 |
| work outside | neutral to cold | 16-22 |

Table 2.4 Activities and affiliated PET values with the thermal sensation, these values were calculated based on measurements of different investigations in Germany (Katzschner, 2004)

Moreover, the concept of thermal preferences were developed to analyse design problems regarding the thermal environments in urban spaces and to give useful design advices. Thermal references can be defined as *"the combination of physical factors influencing thermal sensation (air temperature, humidity, air movement, radiation, clothing and activity) which a person in a particular physical environment would choose when constrained by climate and existing physical, social, cultural and economic influences, including general social expectations of the urban space";* which included real-world considerations and related to thermal attributions of the three environments, namely climatic, built and human environments (Erell et al., 2011). This shows the complexity of people's perceived thermal comfort and their thermal preferences, which involves the interrelationship between physical, physiological, social, behavioural and psychological parameters.

It is suggested that the consequences of improving thermal conditions for humans are even greater than reducing the air temperature alone, due to people's perception are significantly influenced by different environmental cues and thus not always in accord with the actual temperature. Accordingly, the perceived thermal comfort conditions are considered more relevant to the design process. (Lenzholzer, 2009; Matzarakis & Amelung 2008)

In sum, according to the earlier studies, it is expected that people's perceived thermal comfort is related to individual positive experience and aesthetic appreciation of outdoor spaces, and at the same time affected by their spatial perception of the environment (Klemm et al., 2015a).

Perceived thermal comfort play a significant role in developing climate-adaptive urban environments and as an essential factor to evaluate the quality of outdoor spaces. Especially most of the cities are affected by urban heat island, which threatens human health and well-being. Thus, it is necessary to understand and to consider the effects of perceived thermal comfort as a guide to develop urban outdoor spaces by investigating the interrelation between physical, physiological, behavioural and psychological parameters.

### *2.2.3 Causes of urban heat island formation and the heat mitigation measures*

The formation of urban heat islands reflects the sum effect of the multitude of man-made alterations and involves many controllable and uncontrollable factors. People developing the city and keep changing the the forms of physical environments that affects the surface energy balance, which refers to the heat generated and contained by an area from various sources. This means that the formation of urban heat islands can be observed by comparing the differences in surface energy balance between urban area and non-urbanised rural surroundings (Figure 2.6) (Erell et al., 2011; Rizwan et al., 2008).

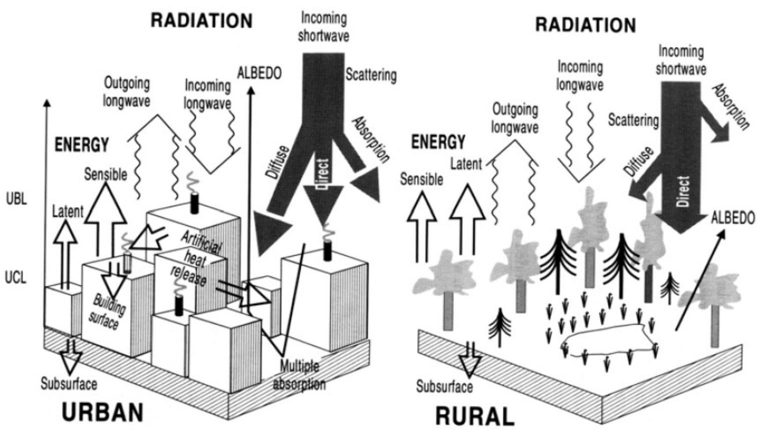



Figure 2.6 Radiations and energy fluxes over an urban and a rural area on a clear day which contributes to the formation of urban heat islands; the width of the arrows approximates the size of the flux (adapted from Oke, 1988; cited by Gill et al., 2004)

In general, the causes of urban heat island formations and the factors affecting their intensity were summarised as: (1) urban form, (2) building density, (3) impervious surfaces, (4) vegetation, (5) properties of urban materials, (6) heat released by human activity which are the controllable factors while (7) weather and (8) geographic location are the uncontrollable factors (Erell et al., 2011). However, in many existing urban areas where the built form is already established, not all these factors are immediately changeable nor improvable in the short term for tackling the heat island effect.

Therefore, those factors were further categorised into three parts including five factors considering the practical aspects in terms of time and feasibility.

The first part includes (1) reduced vegetation in urban areas and (2) properties of urban materials. Urbanisation replaces natural surfaces (i.e. surfaces covered with vegetation) by impervious urban surfaces (i.e. concrete and asphalt in the form of roofs, pavements, roads and parking lots etc.). As a result, the city lost the benefits offered by vegetation such as the cooling effects provided by trees through shading and evapotranspiration to moisture the surrounding air, rainwater interception, storage and infiltration functions.

Meanwhile, the thermal properties of building and paving materials in terms of solar reflectance, thermal emissivity, and heat capacity influence the absorption of solar radiation and energy, and then heat up the environment both directly and indirectly. These two are the considerable factors which can be improved by greening interventions for rapid improvement, and also are the main focus for the community.

The second part concerns (3) urban geometry and (4) anthropogenic heat emissions. On the one hand, urban geometry usually refers to height-to-width ratio (H/W) and sky view factor (SVF) of the street, orientation and building density, which influences the amount of solar energy trapped within street canyons. On the other hand, anthropogenic heat refers to the heat generated by human activities, particularly for transportation, industrial processes, heating and cooling purposes (e.g. the use of air conditioners), which relates to a variety of urban activities and infrastructures. These two factors are relatively fixed and involved a larger scale of modification, and hence were categorised as the factors to be considered for the future development.

The last part involves (5) some additional factors such as weather and geographic location. Wind and cloud cover are the primary weather characteristics which intensifies the heat island effects. For example, the magnitude of urban heat islands are largest under calm and clear weather conditions. Geographic location of the city refers to the regional climate and topography of the area. Besides, even the season and time of day have an influence on the intensity of urban heat islands. Nonetheless, these factors are identified as uncontrollable and excluded from the following discussion of mitigation measures (Erell et al., 2011; EPA, 2008a).

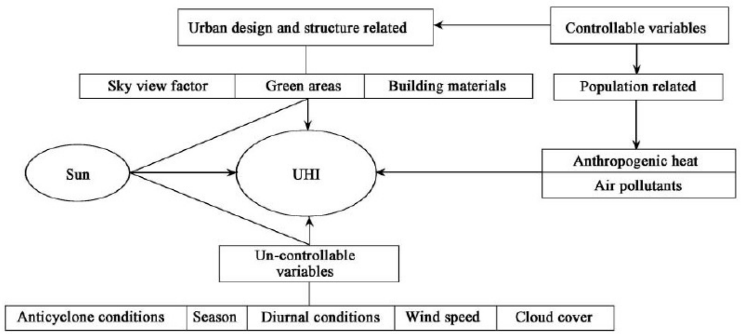



Figure 2.7 The formation of urban heat islands (Rizwan et al., 2008)

According to Rizwan et al. (2008), the formation of urban heat islands involves controllable and uncontrollable factors (Figure 2.7). Most of the controllable factors are planning and design related and to some extent could be humanly modified by taking actions; whilst the uncontrollable factors are generally environment and nature related which are out of human control.

In general, the possible heat island mitigation measures are focusing particularly on anthropogenic heat, surface albedo, and evapotranspiration. Accordingly, the heat mitigation measures could be broadly categorized as: (1) reducing anthropogenic heat and energy consumption (e.g. by controlling the use of cooling facilities and by developing energy efficiency technologies in the design of buildings and motor vehicles etc.), (2) increasing the surface albedo to control the solar gain (e.g. by using specially engineered pigments for albedo enhancement and by replacing the highly absorptive materials such as asphalt and dark-coloured building surfaces with lighter and more reflective materials for roofing and paving), (3) enhancing evapotranspiration (e.g. by planting and enriching vegetation covers).

Among the three mitigation measures, anthropogenic heat was reported has a smaller effect than albedo and vegetation covers (Rizwan et al., 2008; Taha, 1997) However, the application of these strategies for heat mitigation significantly depends on the climatic context and site-specific characteristics, which involves a complex interrelation between physical environment and varied controls. That is to say, it is crucial to take the local factors into consideration in order to develop the most suitable measures for mitigating the heat within the city.

## 2.3 Benefits of Different Types of Urban Vegetation on Thermal Comfort and Attractiveness of Outdoor Spaces

It has been amply demonstrated that urban vegetation is effective in physically improving outdoor thermal comfort (Bowler et al, 2010; Lin et al., 2008; Alexandri & Jones, 2008; Gill et al., 2007; Dimoudi & Nikolopoulou, 2003). But also beautifying the streetscape in the psychological terms, especially in relation to people's visual perception (Klemm et al., 2015ab; Qin et al., 2013; Lafortezza et al., 2009; Smardon, 1988; Ulrich, 1986). In con-sequence, urban greening is regarded as the most promising heat mitigation measure concerning the financial aspects and its flexibility in adapting to the existing urban built form (Rizwan et al., 2008; Gill et al., 2007; Ulrich, 1985; cited by Smardon, 1988), also as a climatic component in the design of thermally comfortable and attractive outdoor spaces.

### *2.3.1 Physical and psychological functions of urban vegetation*

*- Physical functions of urban vegetation*

The microclimatic effect of vegetation and its contribution to urban environment has been adequately proved. The physiological characteristics of vegetation which helps to regulate the climatic conditions are classified into four aspects represent the different functions:

First, the evapotranspiration process to decrease temperature by releasing water vapour to the surrounding atmosphere. Second, transmission of vegetation, deciduous trees in particular, related to solar and daylight access varies with the season, which also determines the shading pattern. Third, albedo refers to solar reflectance from vegetative surfaces and canopies. Apart from that, much of the solar energy is found in the visible wavelengths, this means that the colours of leaves influence the vegetation albedo as well. Last but not the least, the permeability of vegetation to wind that affects the airflow within street canyons (Dimoudi & Nikolopoulou, 2003).

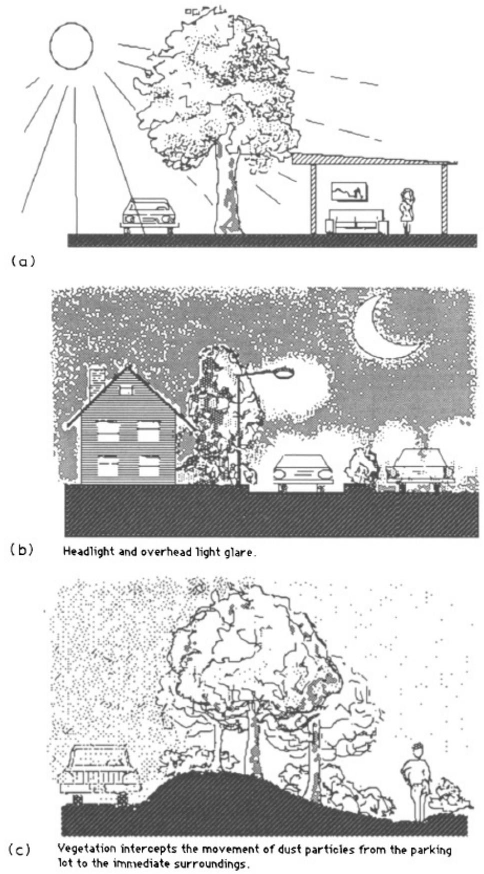



Figure 2.8 Physical functions of urban vegetation (a) production of shade; (b) glare reduction; (c) interception of dust (Smardon, 1988)

Furthermore, Aloys (1982) summarized six vegetation activities that involves to bring positive climatic effects, which are: (1) air cooling, (2) increase in the relative air humidity, (3) fresh air supply, (4) air filtration, (5) noise absorption, and (6) oxygen production.
In view of these characteristics and physical functions of vegetation (Figure 2.8), the climatic use of plants is a considerable approach to improve thermal environment. However, it must be noted that the magnitude of the effect have a strong correlation with other meteorological variables such as wind and sunlight and the surroundings (Figure 2.9).

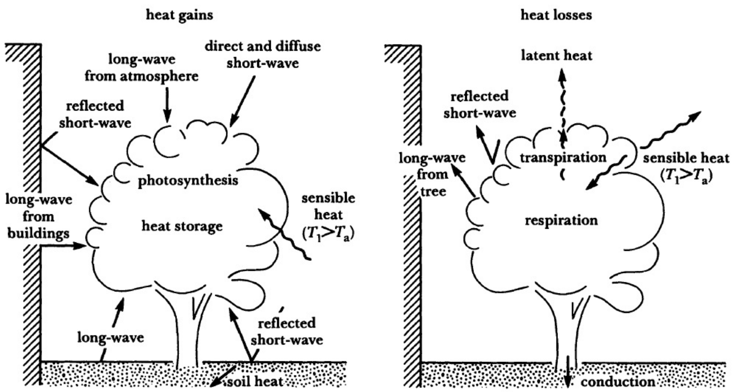



Figure 2.9 Scheme of the daytime energy exchanges between isolated tree and its street canyon environment (Oke et al., 1989)

*- Psychological functions of urban vegetation*

Studies on the contribution of street greenery to people's perception and response to the environment indicated that the aesthetic quality and appreciation of urban scenes usually increases when trees and other vegetation are present (Ulrich, 1986; Thayer & Atwood, 1978). People's aesthetic appreciation of the environment is significantly based on their visual perception due to vision provides more information than the other senses combined (Klemm et al., 2015b; Carmona, 2010; Velarde et al., 2007). Accordingly, one of the beneficial functions of urban vegetation is visual screening, by using vegetation to mask unpleasant urban scenes such as heavy traffic roads and parking lots in order to enhance user enjoyment. Besides, vegetation can function as natural buffer to visually obstruct incompatible land uses as well as to physically separate different functional zones (Smardon, 1988; Brush et al., 1979; Thayer & Atwood, 1978), as shown in figure 2.10.

Thayer & Atwood (1978) summarised the benefits of urban vegetation on aesthetic quality and people's preference for vegetated environments can be optimised *"by adding, subtracting, or interacting with other landscape elements"* (Robinette, I 972; cited by Thayer & Atwood, 1978) in order to integrate different elements and to diversify the streetscapes.

To sum up, street greenery contributes to physical thermal comfort by providing shade and cooling the air through evapotranspiration; and in the meantime benefits psychological well-being associated with the use of green spaces and views containing trees and other vegetation.

Although the large amount of street greenery accumulates thermal benefits from the physical functions of vegetation. However, the sum effects in terms of perceived thermal comfort and aesthetic appreciation were assumed to be affected by psychological factors. As Hellinga (2013) pointed out that people prefer the view includes more information, which means too much vegetation might block their view and decrease the sense of security.

Also views totally filled by vegetation are generally not appreciated by people (Meerdink et al., 1988; cited by Hellinga, H., 2013). All these factors have impacts on people's perception and therefore could be influencing individual experiences in terms of perceived thermal comfort and environmental satisfaction. It is essential to consider both aspects and the interaction between physical and psychological parameters for creating a thermally comfortable and attractive urban streets.

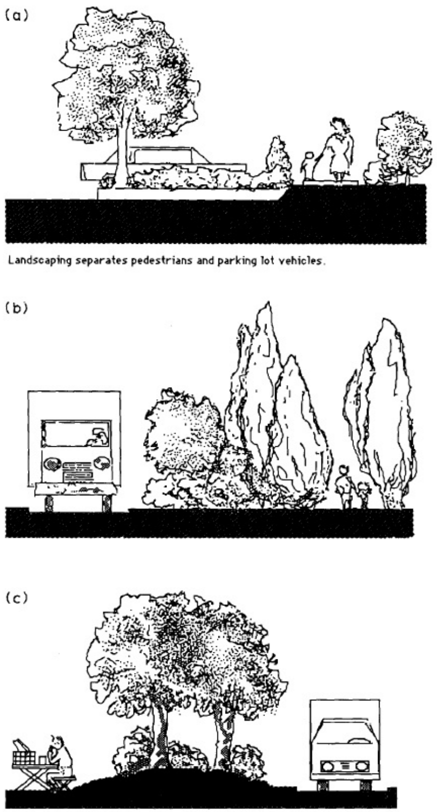



Figure 2.10 Psychological functions of urban vegetation (a) screening parking lots; (b) screening traffic; (c) aesthetic and sensory environment (Smardon, 1988)

### *2.3.2 Typology of urban vegetation*

The typology of urban vegetation can be identified from different perspectives.
On the one hand, Dimoudi & Nikolopoulou (2003) seen vegetation as separate entities in different dimensions and simply characterised vegetation as (1) planar objects (e.g. grass, planted pergolas) and (2) 3D objects (e.g. trees, shrubs). This reveals the generic forms of vegetation and its physical characteristics. Planar objects represents the vertical and horizontal features while 3D objects refers to the green volume.

On the other hand, Bowler et al. (2010) reviewed the most common used greening in-terventions for cooling the city and categorised the urban vegetation into four types: (1) ground vegetation, (2) wall or roof vegetation, (3) trees, (4) parks or green areas which were usually a mixture of ground vegetation and trees. The results are shown in figure 2.11.

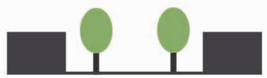
| Type | Diagram | Forms |
|---|---|---|
| Ground vegetation |  | A plot of grass |
| Wall or roof vegetation |  | Green walls; green roofs |
| Trees |  | Single or clusters of trees; forests |
| Parks or green areas |  | Front gardens |

Figure 2.11 Visualization of the four urban vegetation types according to Bowler et al. (2010)

The present study applied Bowler's categorisation to investigate the different greenery types and their effects on perceived outdoor thermal comfort and attractiveness in urban canyons.

### *2.3.3 Ground and low-height vegetation*

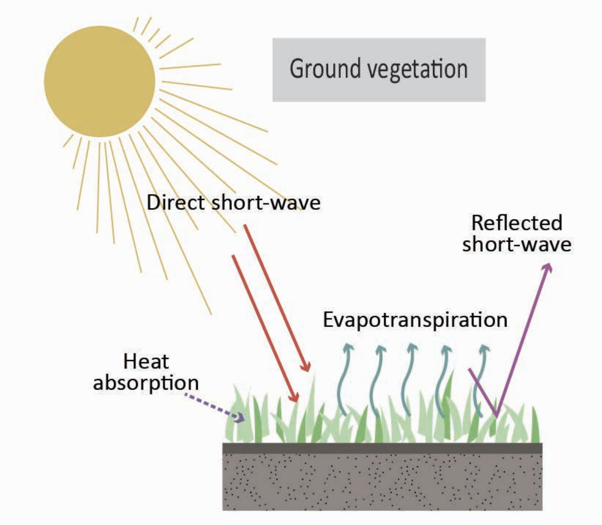



Figure 2.12 Physical functions and thermal benefits of ground and low-height vegetation

The thermal effect of ground vegetation, grass in particular, were frequently compared with other common ground surface materials with different thermal and radiative properties in order to evaluate their influences on temperature. Grass has the highest leaf area density and high albedo which helps to increase relative humidity of the air through evapotranspiration and to reflect the solar radiation and absorb the heat (Figure 2.12) while other impervious surfaces such as asphalt and concrete are usually in dark colours and with low albedo. As a result, it is observed that ground covered with grass contribute to avoid high surface temperature, and at the same time lower the air temperature above the grass cover. However, the evaporative cooling effect of grass were found the largest during the day, due to the vegetation are not physiologically active at night. Therefore, the surface temperatures between different ground surface materials were observed similarly during the night (Lin et al., 2008; Bowler et al., 2010; Lin et al., 2010).

Low-height vegetation (e.g. shrubs, bushes, hedges, and planting beds etc.) adds volume to the flat grass covered ground but not over shaded the space when it is unnecessary. It provides diversity of plant species with different heights and varied forms that can be used to fit into different built environment and to enrich visual perception of the street greenery, which helps to increase aesthetic appreciation of the urban street (EPA, 2008b).

Concerning people's perception of ground and low-height vegetation, in general, grass correlates positively with outdoor activities (e.g. resting, sun-bathing, reading, eating, sleeping etc.); whilst low plants such as shrubs are relatively negatively associated with most activities due to it takes up the room available for activity. However, earlier studies suggested that the neighbourhood scenes consisted of empty grass field without trees or shrubs were not preferred by residents (EPA, 2008b; Smardon, 1988). It is important to take advantage of grass and low plants simultaneously and to combine the green elements for creating an enjoyable environment.

### *2.3.4 Wall and roof vegetation*

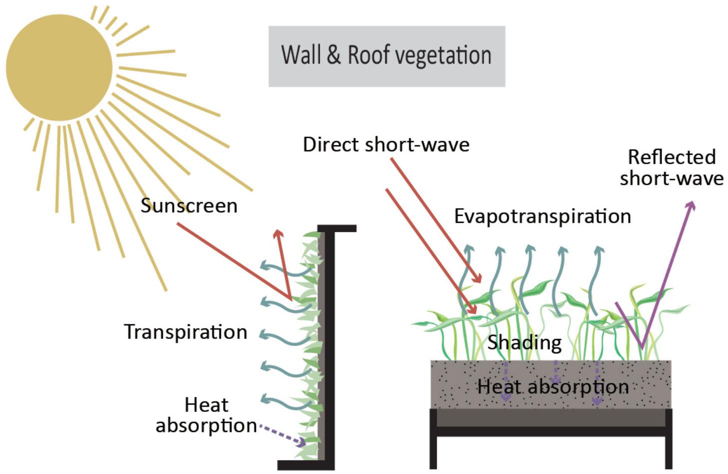



Figure 2.13 Physical functions and thermal benefits of wall and roof vegetation

Green walls and green roofs decreases the surface temperature and cools the air by providing shade and evapotranspiration. Also, the building surfaces covered with vegetation blocks the direct sunlight and thus have an influence on both indoor and outdoor thermal conditions (Figure 2.13). Yet the temperature difference depends on the time of day or the month of the year (Bowler et al., 2010). In addition, the filtration process of vegetation surfaces contribute to the improvement of air quality.

In general, wall and roof vegetation are adaptable to different contexts and can be applied in places with little available space or soil (EPA, 2008b). The shading effects of green walls or green façades are directly influenced by the plant species and its growing characteristics such as seasonal variation. For example, a UK-based research pointed out that during the hottest months of the year (i.e. July, August and September) are exactly the same period of peak growth of climbing plants, which fulfils the need for solar shading in response to the warmer climatic condition. Virginia Creeper is selected as an appropriate plant for growth in the UK climatic condition, which is identified as a mild oceanic climate (Cfb) (Ip et al., 2010).

Wall and roof vegetation represents vertical and horizontal features of green elements in different levels. Green walls have a stronger effect within urban canyons than green roofs that reduces the air temperature as well as surface temperature and benefits pedestrians' perceived thermal comfort; while the thermal effect of green roofs can reach a higher layer of atmosphere above the canyon, of the magnitude of up to 10°C at 4 metres height (Alexandri & Jones, 2004), and therefore have less influence on the pedestrian. In general, green walls and green roofs have lower effect on temperature reduction in a wider canyons because of the large urban surfaces are likely to increase the amount of solar gain. Meanwhile, wider canyons resulted in weaker observable effects from the green walls and green roof, and thus receives less attention with respect to people's perception (Clark et al., 2010; Alexandri & Jones, 2008).

Overall, covering the existing building surfaces with vegetation in the form of green walls, green façades and green roofs could be a realistic strategy for heat mitigation as well as for thermal comfort and aesthetic improvement. It is suggested that people's perception associated with thermal comfort and attractiveness can be enhanced by greening the built environment and increasing urban biodiversity.

### 2.3.5 *Trees*

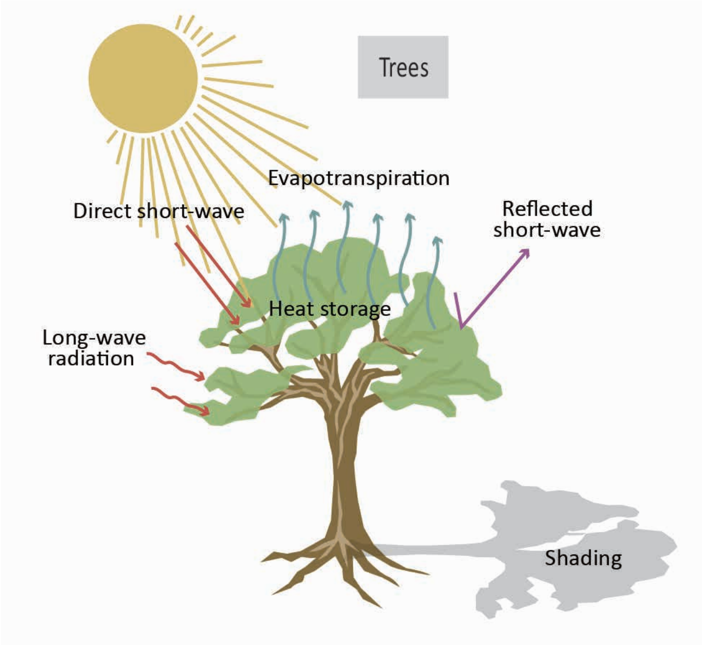



Figure 2.14 Physical functions and thermal benefits of trees

Street greenery in the form of trees has a considerable positive influence on urban microclimate mainly through evapotranspiration and shade production. Moreover, trees sheltered people from the direct sunlight during the warm summer days and protected them from strong wind and rain. In the summertime, generally 10 to 30 percent of the solar energy reaches the area below a tree owing to the trees reflected the short-wave radiation and the tree leaves absorbed the heat (Figure 2.14). However, the amount of solar access through the canopy varies based on plant species (EPA, 2008b).

It is clear that the physical functions of trees are significant for thermal comfort improvement. Lin et al. (2008) has compared the physical thermal effect between the three types of urban vegetation, namely grass, shrub and tree. The results show that tree is the most effective vegetation types in improving thermal condition due to the high evaporation rate. Even the cooling effects (i.e. the production of shade) are largely influenced by wind pattern, the hourly movement of the sun, and building orientation; the overall effect of trees is still greater than the others (Lin et al., 2008).
In the meanwhile, it is widely accepted that the presence of vegetation, especially trees, positively affects people's preference for their living environment in aesthetic terms.

Some studies have compared the temperature difference between below-canopy and open-field (Renaud et al., 2011) and the influence of single and small clusters of trees (Streiling & Matzarakis, 2003). In general, the physiological equivalent temperature (PET) showed distinct differences between areas with trees and areas without trees, except for some relatively small investigation areas. The results show that temperature are generally cooler beneath the trees inside the tree crowns.
According to the measurement conducted in Germany, the average differences in air temperature were 1.0°C and 0.9°C between areas with trees and areas without trees, respectively. In addition, it is observed that the mean air temperature under the cluster of tree crowns were 0.1°C lower than under the single tree (Streiling & Matzarakis, 2003). However, Bowler et al. (2010) has clarified the difference in temperature mostly occurred during the day,

when the trees are most physiologically active, but not in the early morning or at night.

Many studies have focused specifically on trees to examine its thermal effects and to investigate the correlation between people's perception and environmental amenity. The aesthetic elements and characteristics of trees such as lines, forms, colours and textures are the perceptual factors determines people's perception and hence affects their preferences (Muderrisoglu et al., 2009; Smardon, 1988). Different tree forms were evaluated and the results show that trees with spreading canopies were preferred more than trees with columnar and conical forms in terms of people's emotional response and aesthetic preference (Lohr & Pearson-Mims, 2006). However, there are wide regional variations in the results regarding people's aesthetic appreciation. For instance, a Turkey-based research reported that pyramid-formed trees were preferred most for people's visual perception (Muderrisoglu et al., 2009). In general, trees in light green colours were found to have the highest visual quality and tend to make people feel more thermally comfortable.

Furthermore, the thermal effect of tree species with different characteristics such as leaf textures and canopy sizes on microclimate improvement through evapotranspiration are investigated. For example, a study carried out in Greece reported that Ficus species has the highest amount of evapotranspiration, which means it is effective to increase the humidity of the dry summer atmosphere and regulate the temperature, followed by pine, palm, bitter orange and olive (Georgi & Dimitriou, 2010).

The positive effects of trees derived from directly use of trees (e.g. planting in the garden, staying inside the tree crowns etc.) but also visually effective when the trees are in people's visual field. It is suggested that good visibility of urban vegetation lead to a better thermal perception, especially trees due to it is the most visible green elements within canyons (Klemm et al., 2015b; Muderrisoglu et al., 2009; Smardon, 1988). Besides, trees contribute to the aesthetic quality of the environment by adding green volume, visual diversity and complexity to the urban streets.

## 2.4 Effects of the Interaction between Urban Built Form and Vegetation on Thermal Comfort in Street Canyons

The climatic performance of street greenery is significantly affected by the existing urban built form and land use, particularly in temperature variation due to the amount of solar radiation received by building surfaces within urban canyons (Shishegar, 2013; Alexandri & Jones, 2008; Ali-Toudert & Mayer, 2006 & 2007; Eliasson, I., 1996). Different spatial characteristics of street canyons such as aspect ratio (or height-to-width ratio, H/W) and orientation are influential in shaping shadow and wind patterns which affects microclimatic conditions at street level. In the meantime, the thermal properties of urban surfaces and vegetable covers determine people's perceived thermal comfort in urban outdoor spaces.

Increasing vegetation covers is considered as one of the most effective measures to mitigate heat islands and to improve outdoor thermal comfort. However, most of the

cities has established its built form already result from previous development and hence there is limited room for creating new green spaces. Therefore, greening the existing urban surfaces and structures such as roofs, walls, building façades and railway lines are feasible greening interventions for adapting different types of green elements to the existing urban fabric.
In addition, it is important to take the local factors into account in the design of street greenery; by preserving the existing green areas to maintain the original vegetation structure, extending the green volumes and enhancing its positive effects, especially on thermal comfort and human well-being (Clark et al., 2010; Gill et al., 2007).

Lehmann et al. (2014) identified a series of urban vegetation structure type (UVST) which enables the specification and description of different areas within a city characterised by vegetation according to type, size, structural characterisation as well as density, structure and building type. This analytical method was developed as an approach to evaluate the microclimatic effects of different urban vegetation structures, and based on that to facilitate determination of the amount of surfaces covered by vegetation, green volumes and the proportion of sealed surfaces for urban green space planning (Lehmann et al., 2014).

The interaction between urban built form and different greenery types directly influences people's perception of street greenery and their thermal comfort conditions (Shishegar, 2013; Bowler et al., 2010; Alexandri & Jones, 2008; Ali-Toudert & Mayer, 2006 & 2007).

Studies on effects of street geometry (i.e. aspect ratio, orientation) on thermal comfort in terms of airflow and solar access in urban canyons indicated that the discomfort is expected to increase for wider streets (Ali-Toudert & Mayer, 2007). This is because the temperature within the canyon are dominated by the amount of solar radiation exposed to the street surfaces. Consequently, a wider street is observed that have weaker effects of green walls and green roofs on temperature decrease (Alexandri & Jones, 2008). "In general, green walls had a stronger effect on temperatures within the canyon, while green roofs had greater effect at the roof level and the urban scale" (Clark et al., 2010). Besides, a wider street provides better mixing of air and therefore contributes to good ventilation within the canyon (Shishegar, 2013).

Form a spatial design perspective, in narrow streets, green elements with vertical features such as green walls, green façades and climbing plants are proportionally more dominant on people's perception. By contrast, in wider canyons, green elements with horizontal features such as grass and low-height vegetation such as shrubs, hedges which forms the floor-scape play a prominent role in shaping spatial experience and stimulating people's visual perception owing to the presence of greenery is in their eye-level views (Carmona, 2010). In other words, wall vegetation is expected that have less effects on people's perception in wider canyons. The reason is that the perceptual factors are less observable by pedestrians due to the broad visual angles and the wide opening canyons.

# Reference


**A** Alexandri, E. & Jones, P. (2004). The Thermal Effects of Green Roofs and Green Façades on an Urban Canyon. Proceedings of International PLEA Conference 2004, Passive and Low Energy Architecture. Eindhoven, The Netherlands, 19 – 22.

Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment, 43, 4, 480-493.

Ali-Toudert, F., & Mayer, H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Building and Environment, 41, 2, 94-108.

Ali-Toudert, F., & Mayer, H. (2007). Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons. Solar Energy, 81, 6, 742-754.

Aloys, B. (1982). The contribution of tress and green spaces to a town climate. Energy and Buildings, 5, 1-10.

Armson, D. (2012). The Effect of Trees and Grass on the Thermal and Hydrological Performance of an Urban Area. PhD Thesis, Faculty of Life Sciences. University of Manchester.

Auliciems, A. (1981). Towards a psycho-physiological model of thermal perception. International Journal of Biometeorology, 25, 2, 109-122.

**B** Bazan-Lopes, M. J. (2001). Transformations in port-cities in times of globalisation: the case of the Rio de la Plata Estuary. DUT—Delft University of Technology, Netherlands.

Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landscape and Urban Planning, 97, 3, 147-155.

Brush, R. O., Williamson, D. N., & GY, J. F. (1979). Visual screening potential of forest vegetation. Urban Ecology, 4, 3, 207-216.

**C** Carmona, M. (2010). Public places, urban spaces: the dimensions of urban design. Routledge.

Chen, L., & Ng, E. (2012). Outdoor thermal comfort and outdoor activities: A review of research in the past decade. Cities, 29, 2, 118-125.

Clark, C., Busiek, B., & Adriaens, P. (2010). Quantifying thermal impacts of green infrastructure: Review and gaps. Proceedings of the Water Environment Federation, 2010, 2, 69-77.

**D** Daamen, T. A., & Vries, I. (2012). Governing the European port–city interface: institutional impacts on spatial projects between city and port. Journal of Transport Geography.

Deb, C., & Ramachandraiah A. (2010). The significance of Physiological Equivalent Temperature (PET) in outdoor thermal comfort studies. International Journal of Engineering Science and Technology, 2, 7, 2010, 2825-2828.

Diedrich L. (2013). Translating harbourscapes: site-specific design approaches in contemporary European harbour transformation. Frederiksberg: Department of Geosciences and Natural Resource Management, University of Copenhagen.

Dimoudi, A, & Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. Energy and Buildings, 35, 69-76.

**E** Eliasson, I. (1996). Urban nocturnal temperatures, street geometry and land use. Atmospheric Environment, 30, 3, 379-392.

EPA. (2008a). Reducing urban heat islands: compendium of strategies: urban heat island basics. Washington, DC: Climate Protection Partnership Division, U.S. Environmental Protection Agency.

EPA. (2008b). Reducing urban heat islands: Compendium of strategies: trees and vegetation. Washington, DC: Climate Protection Partnership Division, U.S. Environmental Protection Agency.

Erell, E., Pearlmutter, D., & Williamson, T. J. (2011). Urban microclimate: Designing the spaces between buildings. London: Earthscan.

**G** Gaitani, N., Mihalakakou, G., & Santamouris, M. (2007). On the use of bioclimatic architecture principles in order to improve thermal comfort conditions in outdoor spaces. Building and Environment, 42, 1, 317-324.

Georgi, J. N., & Dimitriou, D. (2010). The contribution of urban green spaces to the improvement of environment in cities: Case study of Chania, Greece. Building and Environment, 45, 6, 1401-1414.

Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: the role of the green infrastructure. Built Environment (33):1, 115-133.

Gill, S., Pauleit, S., Ennos, A. R., Lindley, S. J., Handley, J. F., Gwilliam, J., & Ueberjahn-Tritta, A. (2004). Literature review: Impacts of climate change on urban environments. Manchester: Centre for Urban and Regional Ecology, University of Manchester.

**H** Hanna, R. (1996). The relationship between thermal comfort and user satisfaction in hot dry climates. Renewable Energy, 10, 4, 559-568.

Harris, R., & Coutts, A. (2011). Airborne thermal remote sensing for analysis of the urban heat island. Melbourne: School of Geography and Environmental Science, Monash University.

Hayuth, Y. (1982). The port–urban interface: an area in transition. Area, 14, 219–224.

Hellinga, H. (2013). Daylight and view: The influence of windows on the visual quality of indoor spaces. Ph.D. Thesis. Delft University of Technology, the Netherlands.

Hove, B. van, Jacobs, C. M. J., Heusinkveld, B. G., Elbers, J. A., Steeneveld, G. J., Moors, E.J., & Holtslag, A. A. M. (2011b). Exploring the urban heat island intensity of Dutch cities. In: Hebbert, M., Jankovic, V., Webb, B., & University of Manchester (Eds.) (2011). City weathers: Meteorology and urban design 1950-2010. Manchester Architecture Research Centre (MARC), 31-38.

Hove, B. van, Jacobs, C. M. J., Heusinkveld, B. G., Elbers, J. A., Steeneveld, G. J., Moors, E.J., & Holtslag, A. A. M. (2011b). Exploring the urban heat island intensity of Dutch cities. In: Hebbert, M., Jankovic, V., Webb, B., & University of Manchester (Eds.) (2011). City weathers: Meteorology and urban design 1950-2010. Manchester Architecture Research Centre (MARC), 31-38.

Hoyle, B.S., (1989). The port–city interface. Trends, problems and examples. Geoforum, 20, 4, 429–435.

Huang, W. C., Chen, C. H., Kao, S. K., & Chen, K. Y. (2011). The concept of diverse developments in port cities. Ocean and Coastal Management, 54, 5, 381-390.

**I** Ip, K., Lam, M., & Miller, A. (2010). Shading performance of a vertical deciduous climbing plant canopy. Building and Environment, 45, 1, 81-88.

**K** Katzschner, L. (2004). Open space design strategies based on thermal comfort analysis. Proceedings of International PLEA Conference 2004, Vol. 1, 47-52.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015b). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., Jacobs, M. H., & Van, H. B. (2015a). Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment, 83, 120-128.

**L** Lafortezza, R., Carrus, G., Sanesi, G., & Davies, C. (2009). Benefits and well-being perceived by people visiting green spaces in periods of heat stress. Urban Forestry & Urban Greening, 8, 2, 97-108.

Lehmann, I., Mathey, J., Rößler, S., Bräuer, A., & Goldberg, V. (2014). Urban vegetation structure types as a methodological approach for identifying ecosystem services–application to the analysis of micro-climatic effects. Ecological Indicators, 42, 58-72.

Lenzholzer, S. (2009). Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg Nr. 18: long-term microclimate experience in urban public spaces in The Netherlands. 5th Japanese-German Meeting on Urban Climatology, Freiburg, Germany, October 2008. Albert-Ludwigs-University of Freiburg, Germany. 221-229.

Lin, B., Li, X., Zhu, Y., & Qin, Y. (2008). Numerical simulation studies of the different vegetation patterns' effects on outdoor pedestrian thermal comfort. Journal of Wind Engineering & Industrial Aerodynamics, 96, 1707-1718.

Lin, T. P., Matzarakis, A., Hwang, R. L., & Huang, Y. C. (2010). Effect of pavements albedo on long-term outdoor thermal comfort. Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg, 497-503

Lohr, V. I., & Pearson-Mims, C. H. (2006). Responses to scenes with spreading, rounded, and conical tree forms. Environment and Behaviour, 38, 5, 667-688.

**M** Matzarakis, A., & Amelung, B. (2008). Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans. In: Thomson, M. C., García, H. R., & Beniston, M. (Eds.) (2008). Seasonal forecasts, climatic change and human health: Health and climate. Dordrecht: Springer. Chapter 9: 161-172.

Muderrisoglu, H., Aydin, S., Yerli, O., & Kutay, E. (2009). Effects of colours and forms of trees on visual perceptions. Pakistan Journal of Botany, 41, 6, 2697-2710.

**N** Nikolopoulou, M., & Steemers, K. (2003). Thermal comfort and psychological adaptation as a guide for designing urban spaces. Energy and Buildings, 35, 1, 95-101.

Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. Solar Energy, 70, 3, 227-235.

**O** Oke, T. R. (1976). The distinction between canopy and boundary-layer urban heat island. Atmosphere, 14, 4, 268-277.

Oke, T. R., Crowther, J. M., McNaughton, K. G., Monteith, J. L., & Gardiner, B. (1989). The micrometeorology of the urban forest. Philosophical Transactions of the Royal Society B: Biological Sciences, 324, 1223, 335-349.

**P** Pötz, H., Bleuzé, P., Sjauw, E. W. A., Baar, T., & Sherwood, D. (2012). Groenblauwe netwerken voor duurzame en dynamische steden; Urban green-blue grids for sustainable and dynamic cities. Delft: coop for life.

**Q** Qin, J., Zhou, X., Sun, C., Leng, H., & Lian, Z. (2013). Influence of green spaces on environmental satisfaction and physiological status of urban residents. Urban Forestry and Urban Greening, 12, 4, 490-497.

**R** Renaud, V., Innes, J. L., Dobbertin, M., & Rebetez, M. (2011). Comparison between open-site and below-canopy climatic conditions in Switzerland for different types of forests over 10 years (1998– 2007). Theoretical and applied climatology, 105, 1-2, 119-127.

Rizwan, A., Dennis, L., & Liu, C. (2008). A review on the generation, determination and mitigation of urban heat island. Journal of Environmental Sciences (20):1, 120-128.

**S** Santamouris, M., Alvarez, S., Dupagne, A., Hall, D., Teller, J., Coronel, J. F., & Papanikolaou, N. (2000). Environmental site layout planning: solar access, microclimate and passive cooling in urban areas (Vol. 380). Building Research Establishment.

Shishegar, N. (2013). Street Design and Urban Microclimate: Analyzing the Effects of Street Geometryand Orientation on Airflow and Solar Access in Urban Canyons. Journal of Clean Energy Technologies, 1, 1.

Streiling, S., & Matzarakis, A. (2003). Influence of single and small clusters of trees on the bioclimate of a city: a case study. Journal of Arboriculture, 29, 6, 309-316.

**T** Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and buildings, 25, 2, 99-103.

Thayer, R. L., & Atwood, B. G. (1978). Plants, complexity, and pleasure in urban and suburban environments. Environmental Psychology and Nonverbal Behaviour (3):2, 67-76.

**U** Ulrich, R. S. (1986). Human responses to vegetation and landscapes. Landscape and urban planning, 13, 29-44.

**W** Wiegmans, B. W., & Louw, E. (2011). Changing port–city relations at Amsterdam: a new phase at the interface? Journal of Transport Geography, 19, 4, 575-583.

Włodarczyk, A. (2011). New functions for former harbour areas. Examples of adaptation of neglected city spaces. Architecture Civil Engineering Environment, 4, 15-20.



Photo credit: Christy Tang. (2014).

# 3 Questionnaire Study

**Overview**

This study encompasses questionnaire survey of people's long-term thermal comfort and aesthetic appreciation of outdoor spaces in harbour contexts regarding the role of street greenery. In order to collect site-specific data for the follow-up design guidelines generation, the surveys were carried out in October 2014 in the city of Rotterdam, the Netherlands.

In this chapter, the methods and materials of the questionnaire study are introduced step by step. Firstly, the questionnaire design is illustrated in terms of variables, visual stimuli, question setting, layout and general contents. Secondly, some practical aspects are explained such as the target survey participants, different strategies for data collection and analysis. Finally, the survey results are presented comprehensively and subsequently discussed to make critical remarks about the research outcomes and to address potential limitations of the study design.

## 3.1 Methods and Materials

A visual approach to designing the questionnaire was adopted for conducting this research. To explore people's long-term perception, it is important to provide sufficient information about the context setting for stimulating their sensation. People's environmental perception is obviously multi-sensory. However, vision is an influential sense in yielding information about the things around us, especially in outdoor environments (Carmona, 2010; Ulrich, 1979; cited by Velarde et al., 2007).
Also, the environmental preferences derived from the view contains greenery is significantly valued by people in physical as well as in psychological terms (Klemm et al., 2015b; Velarde et al., 2007).

This study investigated people's long-term thermal comfort considering the role of street greenery. In other words, people answered the questionnaire based on their past experiences in a particular physical environment under given circumstances instead of with an accordable situation during the survey. Therefore, the survey respondents were asked to imagine they are walking on the street shown in pictures of the questionnaire on a hot summer day and then to answer the questions.

### *3.1.1 Questionnaire design*

People's thermal perception and aesthetic appreciation in outdoor spaces relating to street greenery were investigated through the questionnaire survey.
The mixed methods of quantitative and qualitative research approaches were applied in the design of the questionnaire. The reason is that *"to include only quantitative and qualitative methods falls short of the major approaches being used today in the social and human sciences"* (Creswell, 2009).

Therefore, the questionnaire consisted of four series of 16 full-coloured images as visual stimuli and two main questions (both closed-ended and open-ended) associated with thermal comfort and attractiveness. People were asked to evaluate the images according to how thermally comfortable and attractive they perceived the street under given circumstances, and then to briefly describe the reasons for their preferences (see the complete questionnaire in appendix II).

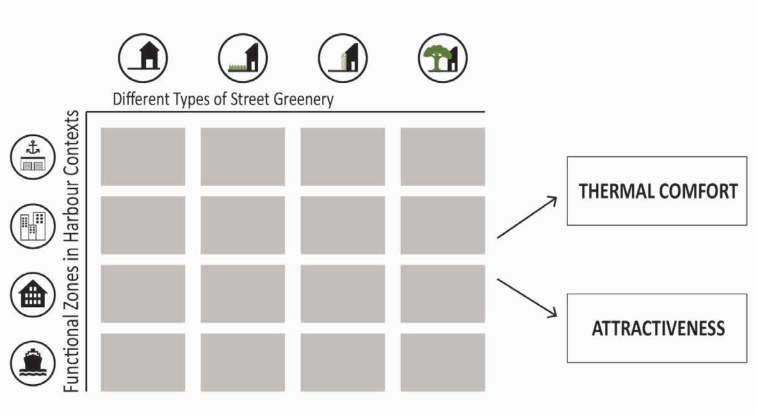


Figure 3.1 Schematic diagram of questionnaire design

*- Variables*

There are two variables involved in the design of this questionnaire: (1) greenery types and (2) functional zones in harbour contexts. The main focus of this study is to investigate what are the contributions of different types of street greenery to improve perceived thermal comfort and attractiveness within urban canyons in harbour areas (sRQ2 & sRQ3). The interaction between these two variables (different greenery types and the spatial characteristics of various harbour functional zones) has considerable influences on determining people's perception (see chapter 2.4).

## Greenery types

Three different types of urban vegetation were used to represent the general green elements at street level, which are (1) ground and low-height vegetation (shorter than 2 metres), (2) wall vegetation and (3) trees based on Bowler's (2010) categorization. Each green element possesses different thermal properties and physical features (i.e. horizontal, vertical, and 3D objects) which are likely to influence people's thermal perception and aesthetic experience visually and spatially.

Roof vegetation has been excluded from the category in this research because the green roofs are usually unobservable by pedestrians and thus it is difficult to evaluate its impact on their perception. Besides, the alternative 'no vegetation' was added in order to make the differences more distinctive.

| | Port-industrial | New business | Residential | Residential waterfront |
|---|---|---|---|---|
| **Building types** | Port-related companies and container buildings | High-rise office buildings and monuments | 4-5 layers houses on both sides | 4-5 layers houses on one sides |
| **Average street width** | 20 m | 30 m | 24 m | 23 m |
| **H/W Ratio** | 1:2.5 | Asymmetrical (with wider canyons) | 1:1.5 | / |
| **Main user** | Workers | Workers and visitors | Residents | Residents and visitors |
| **Roadside Parking** | X | V | V | X |
| **Features** | Visible harbour elements | A mixture of new and old buildings | Neighbourhood with a harbour view | Open waterfront with a harbour view |

Table 3.1 Spatial variables: four harbour functional zones with different spatial characteristic

As a result, four settings of the greenery types were developed, as shown in figure 3.2.

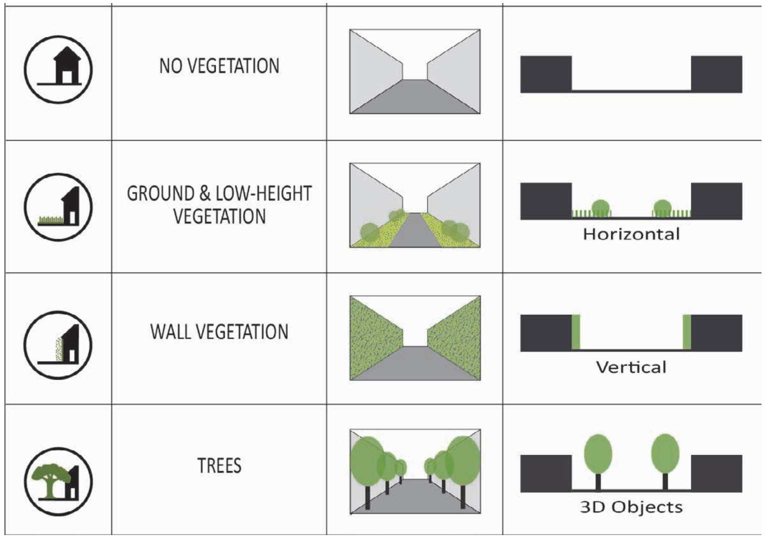



Figure 3.2 Vegetation variables: four alternatives of different greenery types

## Functional zones in harbour contexts

On the basis of literature review (see chapter 2.1.2) and the future zoning plan developed by the municipality of Rotterdam (Figure 5.2), four functional zones in harbour contexts were selected to represent the most common functions adapted to a former harbour area.
That is, (1) port-industrial, (2) new business, (3) residential and (4) residential waterfront. The general spatial characteristics of each functional zone were summarised and the results are shown in Table 3.1.

This section also answered the first sub-research question regarding the typical urban typologies with respect to functions and street configuration extensively applied to the harbour redevelopment projects, which is called the common development orientations.

*- Visual stimuli*

The development of visual stimuli for the questionnaire involve design activity. This reflects the approach *"research through designing"* (see chapter 1.4.3) for conducting this study. The alternatives include the modification of general background images for the four functional zones in harbour contexts and the design of different types of street greenery. The process of developing the visualisation images for the questionnaire is shown in Appendix I.

General background image in four harbour functional zones

The photographs used in the questionnaire were taken in the case study area of Merwe-Vierhavens, Rotterdam.
To avoid the background being an influence and to make the images more comparable, the photos were taken from the same perspective and in the mild weather conditions (Figure 3.3). Besides, the specific elements such as high-rise office buildings, a preserved monument or the port cranes were included in order to provide relevant environmental cues of the four harbour functional zones for helping people to perceive and interpret the images.

However, the four selected streets representing the typical functional zones in a harbour area (port-industrial; new business; residential; residential waterfront) are not based on the current situation. Instead they represent the zoning based on the future redevelopment scenario. Consequently, the background images were slightly modified for fitting into the context settings.

Design alternatives of the street greenery

The background images were processed by using Adobe Photoshop to design the three greenery types: ground vegetation, wall vegetation, and trees respectively. Except for the alternative 'no vegetation', each type covers a wide variety of green elements (e.g. plot of grass, grass pavers, hedges, shrubs, green walls, green façades, climbing plants combined with the street furniture and rows of trees etc.). Besides, the development of different design alternatives related to street greenery concerns the amount of vegetation, the position of trees (e.g. single or rows of trees; located in the middle or on one/ both side(s) of the street) and tree sizes.


Figure 3.3 Selected streets for taking pictures and the photo layout

Furthermore, practical and site-specific image ingredients were selected and used for the visualisation using Adobe Photoshop software. In this way, the imagines are more convincing and it helps to stimulate people's perception and the process of answering the questionnaire.

Within four harbour functional zones (port-industrial; new business; residential; residential waterfront), different greenery types (no vegetation, ground and low-height vegetation, wall vegetation, trees) were used to formulate various settings for the visual questionnaire. Finally, four series of 16 visualisation images were included in the survey (Figure 3.4).

*- Question setting*

This investigation focuses on people's long-term thermal experience instead of momentary thermal perception. A particular physical environment under given circumstances was described as: *"Imagine the temperature is over 25°C and you are walking on this street"*.

This brief sentence guides the survey respondents to reconstruct their previous experiences about walking outside on a warm summer day, followed by the two main questions associated with thermal comfort and attractiveness.

The concept of thermal comfort has been explained in the introduction page of the questionnaire as *"the perception of all kinds of weather aspects like sun, wind, shadow, and humidity...etc."*. People were asked to evaluate each of these images in a 1 to 4 ranking scale, which 1 is the best and 4 is the least for their preferences in relation to thermal comfort and attractiveness.

Four series of 16 visualisation images were evaluated with the same set of questions:

*(1) Please rank the four images in order of how thermally comfortable you would feel on a hot summer day?*
*(2) Please rank the four images in order of how attractive you experience the green design of this street?*

After the images were ranked in order of preferences, people were requested to provide keywords or briefly describe the reasons for their answers. In addition, the background information of the survey respondents such as their age, gender and place to live or work in Rotterdam were also recorded.

*- Layout and general contents of the questionnaire*

The questionnaire consisted of six pages in total.
The first page is a covering letter (Figure 3.5) introduced the background and the aim of this research including a short notion of thermal comfort, indicated the estimated completion time for the questionnaire, clarified the confidentiality and anonymity of the use of provided information, and finally the contact email addresses were given for further questions. The second page is an instruction on filling out the questionnaire (Figure 3.6), followed by four pages that contains the four series of 16 visualisation images (full-coloured; the size of each image is 10 cm×6 cm) with the two questions mentioned above.

Finally, the content of the questionnaire was translated into two languages, both in English and in Dutch, and were exported in portrait orientation on A4 papers.


Figure 3.4 Series of visualisation images featured with different greenery types (from left to right: no vegetation, ground and low-height vegetation, wall vegetation, trees) within four harbour functional zones (from top to bottom: port-industrial; new business; residential; residential waterfront)

**Intro** This research survey is conducted for my graduation project (Wageningen UR Landscape Architecture) and as part of research study of the transformation project of Merwe-Vierhavens for the municipality of Rotterdam. (Gemeente Rotterdam)

The aim of this research is to investigate local people's perception of outdoor spaces. With this survey analyses thermal comfort and attractiveness of outdoor spaces in a harbor area. Thermal comfort refers to the perception of all kinds of weather aspects like sun, wind, shadow, and humidity...etc.

Are you living or working in Rotterdam?
Would you like to share your ideas and experiences by taking part in this survey?

Answering the questionnaire may take about 10 minutes of your time. The information you provide will remain anonymous and only be used for research purpose. Thank you for taking the time to complete this survey and I greatly appreciate your contribution to my research.

WAGENINGEN UR For quality of life

Gemeente Rotterdam

Christy Tang
christy.tang@wur.nl
c.tang@rotterdam.nl

Figure 3.5 Questionnaire covering letter

### 3.1.2 *Participant (sample group)*

The target participants of the questionnaire survey were restricted to a focused sample group of people who are actually living or working in the city of Rotterdam.

Besides, residents from Schiedam (located west of Rotterdam) and Capelle aan den IJssel (situated on the eastern border of Rotterdam) were also included, because those people are spending their time in Rotterdam frequently and therefore well-acquainted with the city.

### 3.1.3 *Data collection*

In order to reach a wide range of people from Rotterdam's population, two methods were applied to spread the questionnaire survey: (1) online and (2) face-to-face surveys. Both were conducted on October 2014. The web survey were available online for a month; while the face-to-face survey were carried out in randomly choosing days during this period of time, mainly depends on the weather conditions, particularly on days without precipitation such as sunny or cloudy days when there are more people spending their time in outdoor spaces.

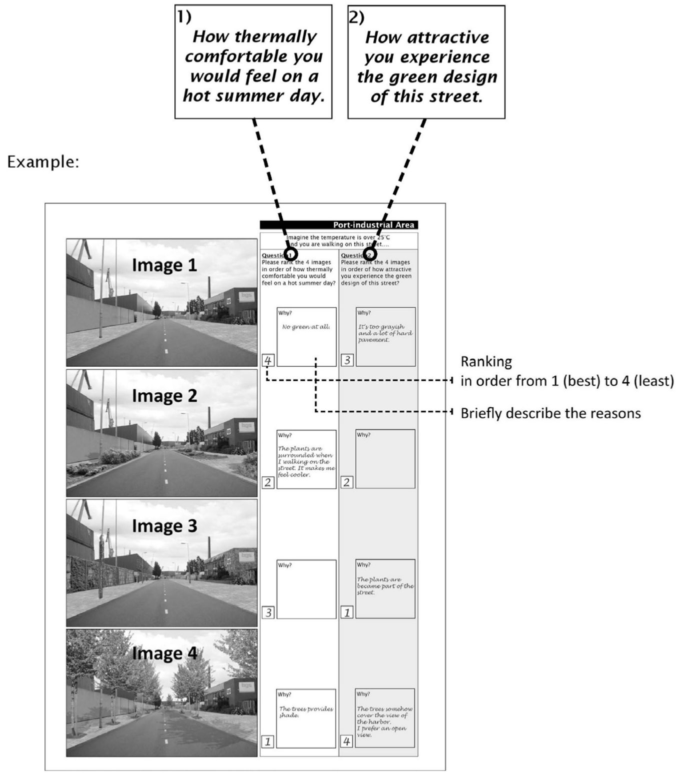



Figure 3.6 Example of how to fill in the questionnaire

*- Online survey*

The content of the online version was exactly the same as the questionnaire, but in a different layout adapted to the template provided by the online survey builder Typeform (http://www.typeform.com/). The online survey was distributed via email to 2 office buildings and 127 local entrepreneurs in the Merwe-Vierhavens area, the mailing lists were obtained through officers who works in the municipality of Rotterdam from different departments and the related association Rotterdam Partners.

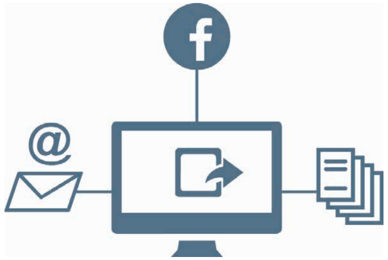


Figure 3.7 Online survey distribution

Also, the online survey were posted on the social networking platform Facebook within specific Rotterdam-based groups and communities. Additionally, 400 printed copies contained essential message of the questionnaire with a URL for the online survey were delivered among the different neighbourhoods all over Rotterdam. In each neighbourhood, addresses were selected using a random-selection procedure based on house numbers.

The online survey are available in two languages.

Dutch version: https://christy9.typeform.com/to/BQrYRB
English version: https://christy9.typeform.com/to/tPBoWQ

*- Face-to-face survey*

The face-to-face survey was performed in English with the full-coloured questionnaire (six A4 pages, see the appendix II) and assisted with two A3 panels show the 16 visualisation images in a bigger size. The survey respondents were selected randomly from the streets within different urban locations described below. Most of the time the answers were written down by the survey interviewer.

When

The field surveys took place between 11 a.m. and 6 p.m. both on weekdays and weekends.

Where

Three main urban locations within the city of Rotterdam were selected to conduct the face-to-face survey (Figure 3.8).

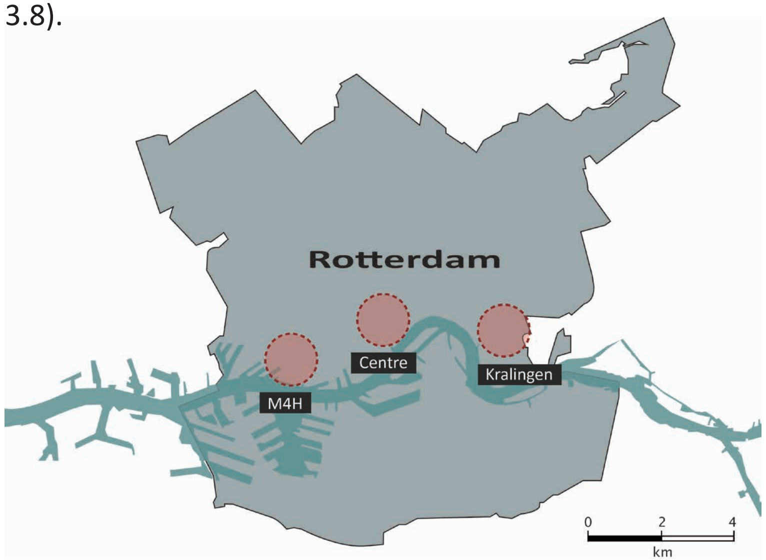



Figure 3.8 Three urban locations in the city of Rotterdam for conducting face-to-face survey

The first one is the surrounding neighbourhoods of the case study area Merwe-Vierhavens (M4H) on the right bank of river Nieuwe Maas in Rotterdam-west. Currently, most of the areas in M4H are occupied by offices and port-related companies, and therefore the area is usually quite empty. Therefore, the face-to-face survey were held on the eastern edge of M4H, where a huge roof park named 'Dakpark' (literally means rooftop park in Dutch) is located between Vierhavensstraat (main road) and Hudsonstraat (residential street). Next to the park is a residential area mixed with neighbourhood parks, school and a promenade along the river Nieuwe Maas.

The second one is the city centre of Rotterdam, particularly on lively streets and urban squares with a mixture of shops, restaurants, cafés and public services such as library and train station.

The third one is Kralingen, a neighbourhood located about 3 kilometres east of the city centre. Also, the area is where the main campus of Erasmus University Rotterdam situated.

### ***3.1.4 Data analysis***

The response outcomes of the questionnaire survey consisted of quantitative and qualitative data, namely the closed-ended rankings and the open-ended reasons for the preferences. Accordingly, two methods were applied to analyse the data: (1) Borda count and (2) qualitative content analysis methods.

*- Ranking (quantitative data)*

The ranking results were calculated and translated into points by adopting Borda count. This positional voting method is used *"to evaluate a finite number of alternatives (e.g. projects, candidates, options, items), with the goal of obtaining an overall ranking of the alternatives"* (Lansdowne & Woodward, 1996).

Borda count is also described as a consensus-based voting system, which can be applied to the context of this research and interpreted as below. The four different settings of the greenery types are the *'candidates'*; the survey respondents as *'voters'*; the points calculated from the ranking represents *'votes'*; and the greenery type received the most points will be the *'winner'*. The aim is to reach a *'consensus'* on people's general preferences in terms of thermal comfort and attractiveness considering the role of different types of street greenery.

The analysis used a formula for counting the total number of points assigned to each greenery type. For example, each setting of the greenery type receives 4 points for being ranked first, 3 points for being ranked second, 2 points for being ranked third and 1 point for being ranked last. As a result, the means and descriptive statistics were produced to describe the data.

*- Reasons for preferences (qualitative data)*

The open-ended reasons for respondents' preferences were categorised and assigned to different themes associated with thermal comfort and attractiveness by using qualitative content analysis methods (Weber et al., 2014; Mayring, 2010).

The respondents put their ideas in the form of words, phrases or sentences to state the reasons behind their preferences, and these information were transcribed and analysed in three steps. First of all, the survey transcripts were categorised by reviewing and identifying the themes

related to the research questions. This analytical process is termed *'coding'* (Mayring, 2010).
Next, the number of times that certain keywords are being mentioned were counted and transformed into measureable numbers which can be used for quantitative analysis. Subsequently, the frequencies were calculated in percentage terms and verified by comparing the results between closed-ended rankings and open-ended reasons in order to have an insight into respondents' preferences and to interpret the data.

## 3.2 Questionnaire Results and Discussion

### *3.2.1 Response outcomes*

A total of 106 valid responses (N=106) were collected through the questionnaire survey, which comprised 64 valid responses obtained from the online survey and 42 valid responses acquired from the face-to-face survey.

The responses outcomes of the face-to-face survey were classified into four groups: valid response, refusal, out of scope and sample loss (Table 3.2). Valid response refers to the correctly completed questionnaire; refusal indicates the selected people were refused to participate due to their personal circumstances (e.g. time issue, uninterested in the topic and language difficulties etc.); Out of scope implies the respondents were not in the target sample group (e.g. tourists from other Dutch cities or abroad); Sample loss means the questionnaires were incomplete and wrongly filled.

*- Non-response rate*

The response rate of face-to-face survey is 44.2%, with a slight majority of refusal (non-response rate 52.6%) that more than half of the selected passers-by were refuse to participate the survey. However, the response and non-response rates mentioned above were only based on the response outcomes gained from face-to-face survey.
The response data obtained from web survey is somehow difficult to specify because it was distributed as an open source (URL) for email receivers or Facebook surfers. In consequence, it is impossible to identify whether the survey is 'refusal' or not being returned resulted from other situations such as undelivered mails with the wrong addresses and the unread emails etc.

### *3.2.2 Survey respondents*

*- Addresses of homes or workplaces of the respondents*

The locations of survey respondents' homes or workplaces were mapped by asking the question *"where do you live or work in Rotterdam"* and people were requested to write down a street name. The results are shown in figure 3.9. According to this map, it is clear that the survey respondents comes from different parts of the city. This means that the questionnaire were evenly distributed in the study area.

| | Refusal | Out of scope | Sample loss | Valid Response |
|---|---|---|---|---|
| Online survey | / | / | / | 64 |
| Face-to-face survey | 50 | 1 | 2 | 42 |
| | | | | |
| Total | | | | 106 |

Table 3.2 Response outcomes (valid responses N=106)

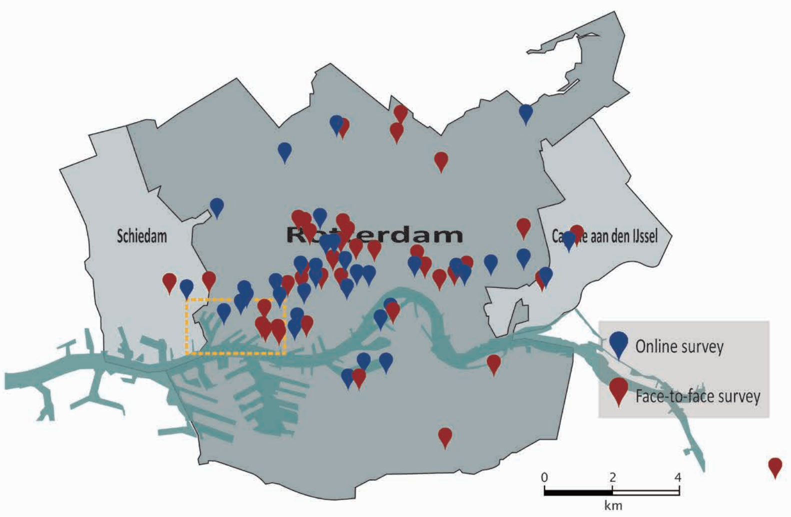
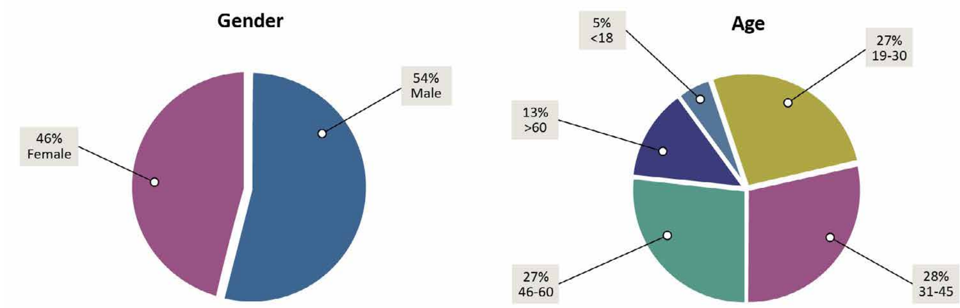



Figure 3.9 Locations of homes or workplaces of the survey respondents in Rotterdam. The pins in different colours refers to the survey respondents approached by using different methods: (blue) online survey and (red) face-to-face survey

*- Age and gender composition of the survey respondents*

The survey respondents were categorised into five age groups, varying between 13 and 83 years old. The mean age of the survey respondents was 41 years old.

The gender composition of survey respondents were almost equal, with a slight majority of male respondents (54%) (Figure 3.10).




### *3.2.3 People's preferences in terms of thermal comfort and attractiveness considering the role of different types of street greenery*

In this section, the questionnaire results were presented as a response to the sRQ 2 & 3. The contributions of different greenery types to thermal comfort and attractiveness in each functional zone were compared and discussed for the development of design guidelines.

The data set consisting of two variables (1) greenery types and (2) harbour functional zones. First of all, the ranking results gave an overview of the general evaluation among the four alternatives of greenery types (no vegetation, ground and low-height vegetation, wall vegetation, trees). Subsequently, the findings were verified by comparing the answers for closed-ended and open-ended questions and demonstrated according to harbour functional zone (port-industrial; new business; residential; residential waterfront). Finally, the link between perceived thermal comfort and attractiveness were discussed according to the questionnaire results.

| **Gender** | **Male** | | **Female** | | **Total** | |
|---|---|---|---|---|---|---|
| **Age** | N | % | N | % | N | % |
| **<18** | 3 | 3 | 2 | 2 | 5 | 5 |
| **19-30** | 13 | 12.5 | 15 | 14.5 | 28 | 27 |
| **31-45** | 18 | 17 | 12 | 11 | 30 | 28 |
| **46-60** | 12 | 11.5 | 16 | 15.5 | 28 | 27 |
| **>60** | 11 | 10 | 3 | 3 | 14 | 13 |
| | | | | | | |
| **Total** | 57 | 54 | 48 | 46 | 105* | 100 |

Figure 3.10 Age and gender composition of the survey respondents
* One missing data on respondent's age was found from the returned online questionnaire. Therefore, the analysis of the age composition was based on 105 age data


Figure 3.11 Rankings of different greenery types from the best (left) to the least (right) in terms of thermal comfort and attractiveness within four harbour functional zones

### *- Closed-ended questions: Ranking*

The preliminary results of the ranking show that people perceived *'trees'* as the most thermally comfortable as well as the most attractive among the other greenery types; whereas the streets contained *'no vegetation'* were always ranked last (Figure 3.11).

Subsequently, the mean points of the different greenery types received in each of the four harbour functional zones were calculated, as shown in Table 3.3.

Overall, the differences of perceived thermal comfort and attractiveness between *'trees'* and *'no vegetation'* were significant; whilst the differences between *'ground and low-height vegetation'* and *'wall vegetation'* were relatively small. *'Trees'* was ranked as the most thermally comfortable and attractive with a mean points 3.84 and 3.68 respectively, by using a four-point scale, which 4 is the highest point.



| Functional Zone | Thermal Comfort | | | | Attractiveness | | | |
|---|---|---|---|---|---|---|---|---|
| | No Vegetation | Low-Height Vegetation | Wall Vegetation | Trees | No Vegetation | Low-Height Vegetation | Wall Vegetation | Trees |
| **Port-Industrial** | 1.13 (.46) | 2.52 (.56) | 2.42 (.63) | 3.92 (.43) | 1.38 (.71) | 2.41 (.80) | 2.50 (.81) | 3.72 (.69) |
| **New Business** | 1.09 (.38) | 2.35 (.55) | 2.74 (.67) | 3.82 (.57) | 1.36 (.73) | 2.30 (.66) | 2.76 (.93) | 3.58 (.78) |
| **Residential** | 1.08 (.39) | 2.35 (.54) | 2.70 (.62) | 3.87 (.50) | 1.27(.63) | 2.37 (.71) | 2.58 (.74) | 3.77 (.65) |
| **Residential Waterfront** | 1.22 (.62) | 2.53 (.68) | 2.52 (.69) | 3.74 (.72) | 1.44 (.81) | 2.47 (.85) | 2.42 (.76) | 3.66 (.78) |
| **Total** | 1.13 (.11) | 2.44 (.07) | 2.60 (.03) | 3.84 (.12) | 1.36 (.07) | 2.39 (.09) | 2.42 (.09) | 3.68 (.07) |

Table 3.3 Mean points of the different greenery types in each of the four harbour functional zones; by using a scale range from 1 (least thermally comfortable to; least attractive) to 4 (most thermally comfortable; most attractive) (N=106, standard deviation in brackets)

Apart from that, the mean points of the four greenery types were rearranged in order and each of the harbour functional zones was distinguished by colours (Figure 3.12). The results of this figure outlined the most favoured greenery types in each functional zones and illustrated the correlation between the different types of greenery and the four functional zones in harbour context. The results were then compared and interpreted according to functional zone, which were demonstrated as follows.

First, in **port-industrial area** (purple) *'trees'* was perceived as the most thermally comfortable followed by *'no vegetation'* and *'ground and low-height vegetation'*; whilst the *'wall vegetation'* received a relatively low ranking in terms of thermal comfort and attractiveness.

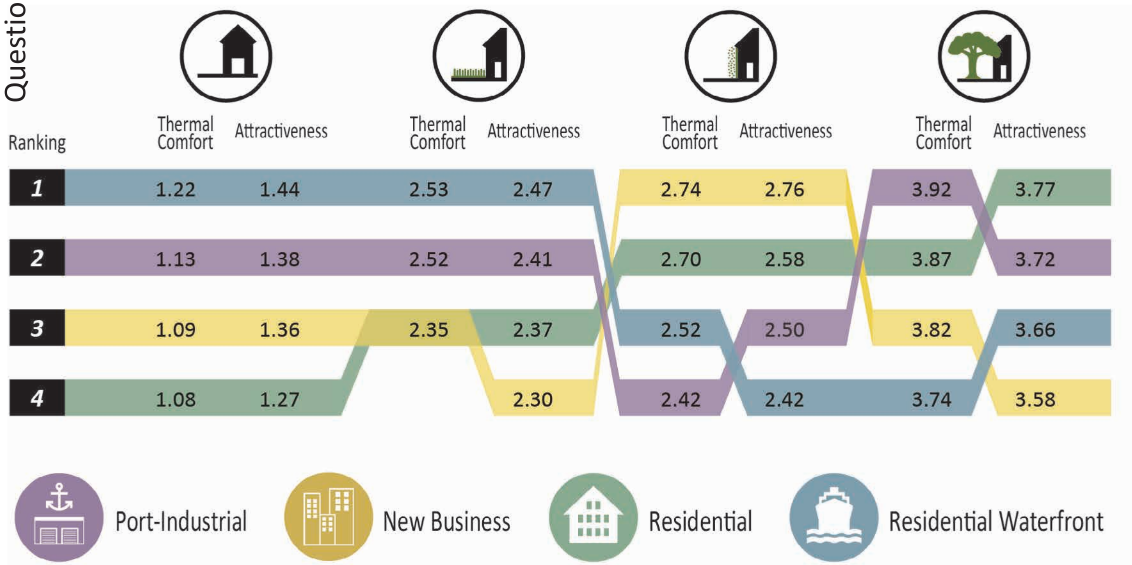



Figure 3.12 Visualisation of the ranking results. Mean points of the four greenery types in each of the harbour functional zones distinguished by colours: (purple) port-industrial; (yellow) new business; (green) residential; (blue) residential waterfront

Second, in **new business area** (yellow) *'wall vegetation'* were considered as both thermally comfortable and attractive greenery type. Third, in **residential area** (green) *'trees'* is extremely attractive with thermal benefits followed by *'wall vegetation'*; whilst *'no vegetation'* was ranked last and therefore must be avoided when planning the residential streets. Fourth, on **residential waterfront** (blue), *'no vegetation'* and *'ground and low-height vegetation'* were perceived as the most suitable for water-related context while the *'wall vegetation'* and *'trees'* received less attention.

Based on these results, a follow-up investigation of the reasons behind people's preferences with relation to thermal comfort and attractiveness were conducted to further discuss the questionnaire results and relate to the relevant literature on thermal benefits and aesthetic values of different greenery types.

*- Open-ended questions: Reasons for preferences*

The results of the open-ended reasons for respondents' preferences were analysed by means of thematic coding and categorising method. All the example of keywords given by the respondents were assigned to at least one of the six themes associated with thermal comfort and attractiveness, as shown in Table 3.4.

Thermal comfort

People considered thermal comfort based on three aspects: the first one is related to *'green infrastructure'* such as the types and amount of vegetation, the planting conditions and the functions of the street greenery; the second one is concerning their *'perception'* both visually

| Thermal comfort | Attractiveness |
|---|---|
| **Green Infrastructure** | **Aesthetic Reasons** |
| - Green types<br>- Amount of greenery<br>- Conditions<br>- Functions<br>- Distance to pedestrians | - Atmosphere<br>- Personal tastes |
| **Perception** | **Design Quality of the street** |
| - Visual<br>*(View)*<br>- Spatial experience | - Visibility<br>*(Visual scale; Openness; Safety; Human scale)*<br>- Imageability<br>*(Sense of place; Characters)*<br>- Usability<br>*(Functions)*<br>- Street furniture<br>- Greenery<br>- Integration<br>*(Fit the surroundings)* |
| **Microclimate Parameters** | **Environmental Benefits** |
| - Wind<br>- Sun<br>- Shade; shadow<br>- Humidity<br>- Surfaces<br>- Rain protection | - Air quality<br>- Ecosystem services<br>*(Biodiversity; Animal habitat)*<br>- Water storage |

Table 3.4 Six thematic categories with relation to thermal comfort and attractiveness for coding

and spatially; the third one is regarding *'microclimatic parameters'* such as wind, sun, shade, humidity and building surfaces.

Each aspect was divided into several sub-aspects for the assignment of keywords. For example, five sub-aspects were labelled as the theme *'green infrastructure'* with respect to thermal comfort. The examples of keywords assigned to each sub-aspect given by the survey respondents are shown in Table 3.5.

| Thermal comfort | |
|---|---|
| **Green infrastructure** | |
| | Keywords |
| **Greenery types** | *lawns; grasses; shrubs; climbing plants; green wall; green screen; green façade; flowers; trees; green pathway; tree lane; horizontal green; vertical green; only grass; only low plants; only greenery on the walls; only trees* |
| **Amount of greenery** | *bald; bare; no nature; no greenery; less green; no enough green; some green; green; greener; lots of greenery; too much greenery; the presence of greenery* |
| **Planting conditions** | *orderly; natural; gross; messy; looks like weeds; too shady; trees cover too much* |
| **Functions of the vegetation** | *protection; trees provide shade and sheltered from solar radiation; evaporation loss of trees; shrubbery reduce heat; leaves absorb heat; greenery can distract my attention from the heat* |
| **Distance to the pedestrian** | *the greenery is closer to people* |

Table 3.5 The example of keywords given by the respondents under the theme *'green infrastructure'* with respect to thermal comfort

### Attractiveness

People evaluated attractiveness of outdoor spaces according to three aspects: the first one is *'aesthetic reasons'* derived from their subjective preferences for the atmosphere of the space; the second one is related to the *'design quality of the street'*, which covers a wide range of considerations such as visibility, safety, usability, sense of place, the design of street greenery and furniture, and whether the design fits its surroundings etc.; the last one some people associated the design of street greenery with *'environmental benefits'* such as air quality, biodiversity, bird habitat and water storage. The complete list of the examples of keywords given by the respondents are shown in appendix III.

The results of respondents' reasons for their preferences and what is the role of different greenery types can play in improving thermal comfort and attractiveness were presented respectively according to functional zone, namely port-industrial area, new business area, residential area and residential waterfront. For each functional zone, the results of the reasons for people's preferences were compared and discussed in relation to the ranking results and linked to relevant studies on the benefits of different types of street greenery on thermal comfort and attractiveness of urban streets (see chapter 2.3).
The frequency of each keywords being mentioned were counted and calculated in percentage terms, as shown in Table 3.6 to 3.8.

*Port-industrial area*

Regarding thermal comfort, *'ground and low-height vegetation'* (mean 2.52) was ranked higher than *'wall vegetation'* (mean 2.42) on a scale range from 1 to 4. On the contrary, *'wall vegetation'* (mean 2.50) has higher rank than *'ground and low-height vegetation'* (mean 2.41) in terms of attractiveness (Figure 3.13).

Generally, people tend to feel more thermally comfortable when the presence of greenery are in their visual field. It also relates to less stone surfaces and pavements. This finding confirms that of an earlier study (Klemm et al., 2015b), which suggested good visibility of street greenery lead to a better thermal perception.

When it comes to attractiveness, people appear to appreciate the streetscape especially when the greenery are integrated into the landscape and reflected the harbour context. This explained the reason why *'wall vegetation'* was ranked higher than *'ground and low-height vegetation'* due to the climbing plants are usually combined with the existing structures such as walls, fences and building façades.
Overall, people consciously aware that the port-industrial zone is a working area, so their expectations of the street were featured with wild landscape and low maintenance greenery, and thus *'naturalness'* (mentioned 8/19 times) and *'fit the surroundings'* (mentioned 16/63 times) are relatively important. For the same reason, *'openness'* (mentioned 14/25 and 10/20 times respectively in terms of thermal comfort and attractiveness) is another key factor for such a working area, in order to keep the harbour functioning but also to provide an open view of the surroundings, therefore, too much green decoration is considered as unnecessary.

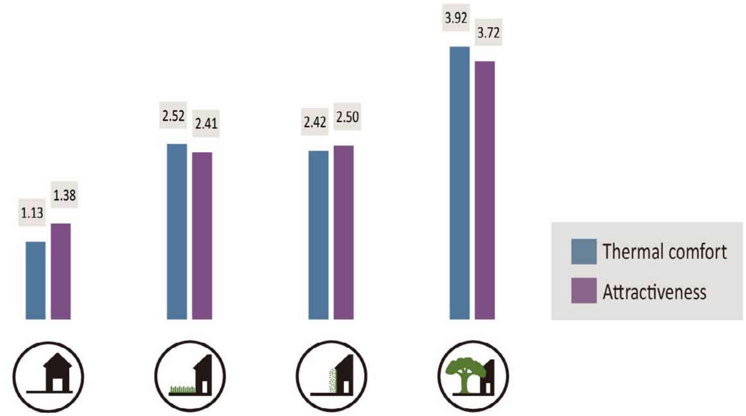



Figure 3.13 A comparison between the different greenery types in terms of thermal comfort and attractiveness in a port-industrial area. The number refers to the mean points on a scale range from 1 to 4

## New business area

Apart from trees, *'wall vegetation'* was ranked the highest in relation to perceived thermal comfort (mean 2.74) and attractiveness (mean 2.76) on a scale range from 1 to 4 (Figure 3.14).

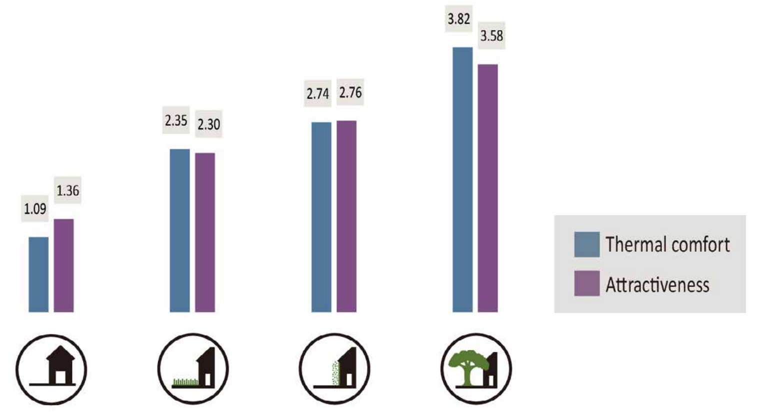



Figure 3.14 A comparison between the different greenery types in terms of thermal comfort and attractiveness in a new business area. The number refers to the mean points on a scale range from 1 to 4

*'Wall vegetation'* was perceived as attractive and significantly valued by people in an aesthetic terms. Because the green elements were integrated into existing urban fabric and shape the atmosphere which is suitable for the business area with a lot of buildings varied of heights. People described the atmosphere as *'modern'; 'professional'; 'innovative'; 'beautiful'; 'inviting'*. This finding confirms earlier studies pointed out that the aesthetic quality and appreciation of the environment can be enhanced by adding, subtracting and interacting with other landscape elements (Thayer & Atwood, 1978).

*'Wall vegetation'* (mean 2.74) was perceived as more thermally comfortable than *'ground and low-height vegetation'* (mean 2.35) owing to the large building surfaces were covered with vegetation, and hence it looks greener and more observable for people. This result is in line with earlier studies on the physical thermal effect of covering the building enveloped with wall vegetation indicated that *"the larger amounts of solar radiation a surface receives, the larger its temperature decreases are when it is covered with vegetation"* (Alexandri & Jones, 2008).

Although *'trees'* received the highest point among other greenery types in a business area, it has a relatively low rank by comparison with the other three functional zones (Figure 3.12). This is because people preferred to have a clear overview of the surroundings which contains sufficient information and environmental cues for them to recognize the place, and consequently *'openness'* (mentioned 7/20 times in terms of attractiveness) is an important quality for a business district. However, people valued the functions of trees to provide shadows for roadside parking as well as for the pedestrian that supports the use of outdoor spaces.

## Residential area

*'Trees'* was top-ranked for improving perceived thermal comfort (mean3.87) and attractiveness (mean 3.77) on a scale range from 1 to 4 (Figure 3.15).

*'Trees'* is the key element to improve thermal comfort in the neighbourhoods owing to the shade provided by trees and it also shelter people from the direct sunlight and the rain. Giving people the feelings *'comfortable'; 'refreshing'* and *'relax'* which is suitable for a living area. Meanwhile, *'trees'* was also perceived as the most attractive greenery types and has the greatest influence on people's

preference. This finding confirms earlier observations indicated that attractiveness was considered as the most important benefits of trees, and usually larger trees are aesthetically preferable than smaller trees (Smardon, 1988).

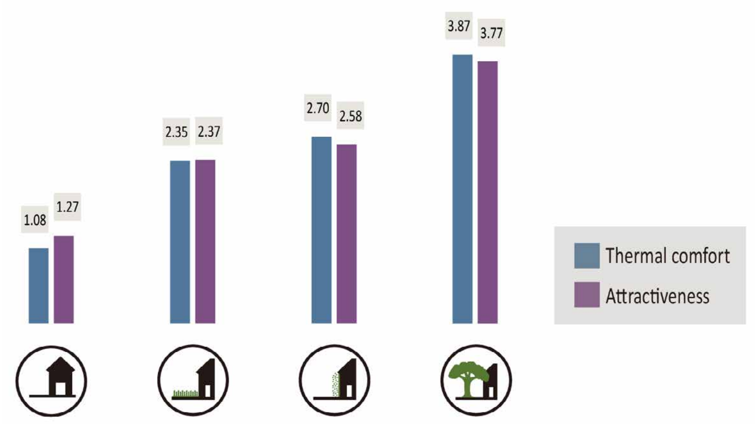



Figure 3.15 A comparison between the different greenery types in terms of thermal comfort and attractiveness in a residential area. The number refers to the mean points on a scale range from 1 to 4

Besides, people addressed *'flowers'* (mentioned 10/16 times), *'colour'* (mentioned 7/20 times) and *'species diversity'* (mentioned 4/16 times) in their neighbourhoods as attractive elements. Because people associated these factors with *'colourful'; 'happiness'; 'cosy'; 'beautiful'; 'delightful'; 'inviting'; 'visually appealing'*. These findings confirms earlier studies pointed out that colour is one of the most influential vegetation characters in determining residents' environmental satisfaction (Qin et al., 2013); and flowers were the most favoured element beneath trees in a residential street. As it not only contributing to the aesthetic quality of the streets but also having a positive effect on psychological well-being (Todorova et al., 2004).

*Residential waterfront*

*'Ground and low-height vegetation'* was ranked slightly higher than *'wall vegetation'* in terms of thermal comfort (mean 2.53) and attractiveness (mean 2.47) on a scale range from 1 to 4 (Figure 3.16).

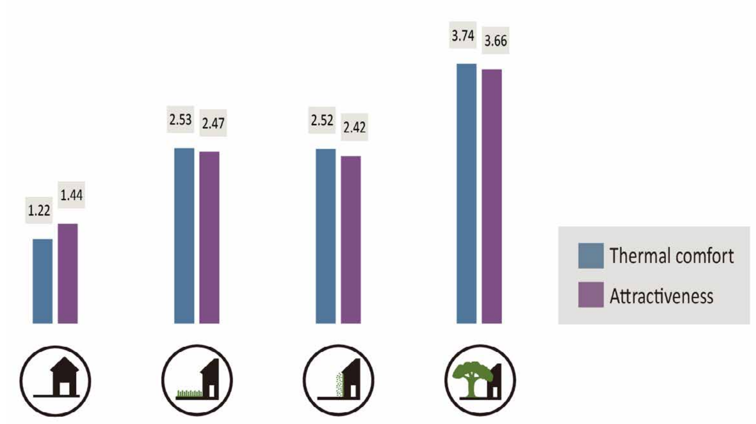



Figure 3.16 A comparison between the different greenery types in terms of thermal comfort and attractiveness in a residential waterfront. The number refers to the mean points on a scale range from 1 to 4

The results show that people relate their thermal perception on the waterfront not only to greenery but also to microclimatic parameters such as wind and water. As a result, an open structure on the waterfront is perceived as both thermally comfortable and attractive because of the ventilation and the view of water. This reflects in the ranking results which *'trees'* received less attention due to the possibilities of obstructing the view.

For the same reason, *'ground and low-height vegetation'* is suitable for the waterfront because it is more visible and people tend to feel cooler when the greenery are at their eye level.

When referring to attractiveness, people considered *'view'* (mentioned 23/41 times) is extremely attractive and as one of the crucial factors in evaluating the quality of the waterfront. Apart from that, people associated waterfront with outdoor experiences which involves varied outdoor activities such as sitting on the grass, reading, eating, cycling along the waterfront and walking under the trees etc. *'Ground and low-height vegetation'* also fit in this case because it can function as a green carpet that keep the space open and leave room for adding leisure facilities on top of it to support those possible activities. In this way, the interaction between people and greenery are also increase. This findings confirms previous studies indicated that grass correlates positively with outdoor activities, whilst shrubs are usually negatively associated with most activities due to their existence reduces the space available for activity (Smardon, 1988).

*- The relationship between perceived thermal comfort and attractiveness*

According to the questionnaire results, among the 106 valid responses, 47% ranked in the same order with respect to thermal comfort and attractiveness for the port-industrial area; 55% for the new business area; 60% for the residential area; 65% for the residential waterfront.

The ranking orders for each functional zones with relation to thermal comfort and attractive were presented nearly the same except for the port-industrial area, which the *'ground and low-height vegetation'* were perceived as more thermally comfortable than *'wall vegetation'* yet less attractive concerning aesthetic appreciation.

This result shows that there is a significant correlation between the perceived thermal comfort and attractiveness. In other words, people considered thermal comfort as a key factor to determine whether an outdoor space is attractive.

| Thermal comfort | Shade | Surfaces | Amount of Greenery | Green Types | Trees | Shelter | Green at Eye Level | Openness | Colour | Wind/ Humidity |
|---|---|---|---|---|---|---|---|---|---|---|
| | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* |
| **Port-Industrial** | 62 *(29)* | 25 *(32)* | 47 *(41)* | 8 *(19.5)* | 27 *(28)* | 10 *(32)* | 2 *(17)* | 14 *(56)* | 5 *(62.5)* | 8 *(29)* |
| **New Business** | 55 *(26)* | 21 *(27)* | 28 *(24)* | 12 *(29)* | 19 *(20)* | 5 *(16)* | 2 *(17)* | 2 *(8)* | 0 *(0)* | 3 *(11)* |
| **Residential** | 54 *(25.5)* | 17 *(21)* | 17 *(15)* | 13 *(32)* | 28 *(29)* | 10 *(32)* | 4 *(33)* | 3 *(12)* | 2 *(25)* | 4 *(14)* |
| **Residential Waterfront** | 41 *(19.5)* | 16 *(20)* | 23 *(20)* | 8 *(19.5)* | 22 *(23)* | 6 *(20)* | 4 *(33)* | 6 *(24)* | 1 *(12.5)* | 13 *(46)* |
| **Total** | 212 *(100)* | 79 *(100)* | 115 *(100)* | 41 *(100)* | 96 *(100)* | 31 *(100)* | 12 *(100)* | 25 *(100)* | 8 *(100)* | 28 *(100)* |

Table 3.6 The number of times being mentioned (N) and the frequency (%) of the keywords associated with thermal comfort

| Attractiveness (Green factors) | Amount of Greenery | Green Types | Trees | Flowers | Species Diversity | Naturalness | Green at Eye Level |
|---|---|---|---|---|---|---|---|
| | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* |
| **Port-Industrial** | 32 *(33)* | 25 *(40)* | 33 *(30)* | 3 *(19)* | 5 *(31)* | 8 *(42)* | 8 *(33)* |
| **New Business** | 24 *(25)* | 14 *(23)* | 26 *(23)* | 1 *(6)* | 4 *(25)* | 4 *(21)* | 5 *(21)* |
| **Residential** | 19 *(20)* | 12 *(19)* | 29 *(26)* | 10 *(62.5)* | 4 *(25)* | 3 *(16)* | 6 *(25)* |
| **Residential Waterfront** | 21 *(22)* | 11 *(18)* | 23 *(11)* | 2 *(12.5)* | 3 *(19)* | 4 *(21)* | 5 *(21)* |
| **Total** | 96 *(100)* | 62 *(100)* | 111 *(100)* | 16 *(100)* | 16 *(100)* | 19 *(100)* | 24 *(100)* |

Table 3.7 The number of times being mentioned (N) and the frequency (%) of the keywords associated with attractiveness (green factors)

| Attractiveness (Other factors) | View | Lightness | Openness | Colour | Activities | Safety | Maintenance | Fit the Surroundings |
|---|---|---|---|---|---|---|---|---|
| | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* | N *(%)* |
| **Port-Industrial** | 7 *(17)* | 1 *(9)* | 10 *(50)* | 3 *(15)* | 4 *(18)* | 1 *(8)* | 4 *(25)* | 16 *(25.5)* |
| **New Business** | 7 *(17)* | 1 *(9)* | 7 *(35)* | 6 *(30)* | 4 *(18)* | 4 *(33)* | 2 *(12.5)* | 16 *(25.5)* |
| **Residential** | 4 *(10)* | 4 *(36.5)* | 1 *(5)* | 7 *(35)* | 5 *(23)* | 2 *(17)* | 8 *(50)* | 19 *(30)* |
| **Residential Waterfront** | 23 *(56)* | 5 *(45.5)* | 2 *(10)* | 4 *(20)* | 9 *(41)* | 5 *(42)* | 2 *(12.5)* | 12 *(19)* |
| **Total** | 41 *(100)* | 11 *(100)* | 20 *(100)* | 20 *(100)* | 22 *(100)* | 12 *(100)* | 16 *(100)* | 63 *(100)* |

Table 3.8 The number of times being mentioned (N) and the frequency (%) of the keywords associated with attractiveness (other factors)

## 3.3 Limitations and Critical Reflections of the Study Design

*- Comparison between online and face-to-face surveys*

In this study, the mixed methods of quantitative and qualitative research approaches were applied for empirical data collection by mean of questionnaire survey.
The distribution of the surveys used two strategies, namely online and face-to-face surveys, in order to reach a wide variety of people and to increase the response rate. To compare these two strategies, each of them reflects different advantages and disadvantages but complementary roles in contributing to the response outcomes.

On the one hand, the main disadvantages of online surveys are the relatively low response rate due to the unpredictable individual circumstances (e.g. unread emails; messages are being ignored; uninterested in the topic etc.) and uncontrollable variations result from less guiding from the survey interviewer such as misunderstanding the questions, incomplete or wrongly filled questionnaire etc. However, people are given freedom in time of answering the questionnaire and this helps to obtain well described and in-depth response outcomes.

On the other hand, the advantage of the face-to-face survey is the interaction between respondent and survey interviewer. The lively process of communication enable the survey interviewer to ask further questions based on certain points provided by the respondents. On the contrary, the main disadvantage of the face-to-face survey is the language barriers. Although most of the respondents can speak fluent English, but they might have difficulties to find the proper English words and express their opinions precisely, and this may lead to a general statement. Additionally, it is observed that the repeating evaluation process may distract respondents' attention, lose their patience and hence influence the response outcomes.

*- Response outcomes*

Regarding the survey outcomes, the questionnaire comprised two main questions associated with thermal comfort and attractiveness, people were asked to answer the questions by first ranking the images and then explaining why. Accordingly, two types of answers were collected and analysed.

It is observed that the ranking results are relatively general, but it provided a basis for the follow-up investigation of the reasons behind people's preferences, and at the same time the reasons contribute meaningful information to understand the research outcomes and give specific design advices. In other words, these two types of answers complement one another by comparing the results and relating to the relevant literature in order to put a comprehensive interpretation on the survey results.

*- Potential difficulties and limitations of applying visual approach to investigate people's perception in terms of thermal comfort and attractiveness*

There are some potential difficulties and limitations associated with the application of a visual approach to investigate people's perception.

One potential limitation concerns the design of the images used in the questionnaire. That is to say, people answered the questions only based on the presented images, and this would lead to bias according to the process of photography acquisition and image editing. Consequently, design and analysis techniques were applied to tackle these limitations by developing different alternatives and performing the sample images among participants to test the efficiency before distributing the final version of the questionnaire (see chapter 3.1.1).

Another potential difficulty in using visual approach to investigate people's perceived attractiveness involves judged complexity. In other words, people's interpretation of images comprises a complex interaction between different greenery types, which is the domain factor in this study, and other design elements contained in the images such as street furniture, house types, water etc. The latter factors also affect the attractiveness perceived by people. However, some of the factors addressed by the survey respondents are uncontrollable (e.g. existing urban built form etc.) and irrelevant to the main focus of this research, which is the design role of street greenery.

In the present study, empirical questionnaire surveys were applied to investigate people's perception of different types of urban vegetation and its effects on their long-term thermal comfort and attractiveness of outdoor spaces in harbour contexts.

Regarding the research methods, it is recommended to use the mixed methods of quantitative and qualitative research approaches to develop the questionnaire survey. The survey comprises closed-ended and open-ended questions helps to interpret the data and to have an insight into the research outcomes. Quantitative and qualitative data have different but complementary roles in answering the questions associated with thermal comfort and attractiveness. By integrating the questionnaire results of these data design guidelines can be generated (see chapter 4).

# Reference


**A** Alexandri, E., & Jones, P. (2008). Temperature decreases in an urban canyon due to green walls and green roofs in diverse climates. Building and Environment, 43, 4, 480-493.

**B** Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. Landscape and Urban Planning (97):3, 147-155.

**C** Carmona, M. (2010). Public places, urban spaces: the dimensions of urban design. Routledge.

Clark, C., Busiek, B., & Adriaens, P. (2010). Quantifying thermal impacts of green infrastructure: Review and gaps. Proceedings of the Water Environment Federation, 2010, 2, 69-77.

Creswell, J. W. (2009). Research design: qualitative, quantitative and mixed methods approaches. Los Angeles, CA: SAGE Publications.

**G** Gill, S. E., Handley, J. F., Ennos, A. R., & Pauleit, S. (2007). Adapting cities for climate change: the role of the green infrastructure. Built Environment 33, 1, 115-133.

**K** Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015b). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., Jacobs, M. H., & Van, H. B. (2015a). Psychological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment, 83, 120-128.

**L** Lansdowne, Z. F., & Woodward, B. S. (1996). Applying the Borda ranking method. Air Force Journal of Logistics, 20, 2, 27-29.

**M** Maas, J., Verheij, R.A., Groenewegen, P.P., Vries, S., de, & Spreeuwenberg, P. (2006). Green space, urbanity, and health: how strong is the relation? Epidemiology and Community Health, 60, 587-592.

Mayring, P. (2000). Qualitative Content Analysis. Forum Qualitative Sozialforschung; Forum: Qualitative Social Research. Online Journal, Vol. 1, 2. Available at: http://qualitative-research.net/fqs/fqs-e/2-00inhalt-e.htm

**Q** Qin, J., Zhou, X., Sun, C., Leng, H., & Lian, Z. (January 01, 2013). Influence of green spaces on environmental satisfaction and physiological status of urban residents. Urban Forestry and Urban Greening, 12, 4, 490-497.

**S** Smardon, R. C. (1988). Perception and aesthetics of the urban environment: review of the role of vegetation. Landscape and Urban Planning, 15, 85-106.

**T** Thayer, R. L., & Atwood, B. G. (1978). Plants, complexity, and pleasure in urban and suburban environments. Environmental Psychology and Nonverbal Behaviour 3, 2, 67-76.

Todorova, A., Asakawa, S., & Aikoh, T. (2004). Preferences for and attitudes towards street flowers and trees in Sapporo, Japan. Landscape and Urban Planning, 69, 4, 403-416.

**V** Velarde, M. D., Fry, G., & Tveit, M. (2007). Health effects of viewing landscapes - Landscape types in environmental psychology. Urban Forestry & Urban Greening, 6, 4, 199-212.

**W** Weber, F., Kowarik, I., & Saumel, I. (2014). A walk on the wild side: Perceptions of roadside vegetation beyond trees. Urban Forestry & Urban Greening, 13, 2, 205-212.

Photo credit: Christy Tang. (2014).

# 4 Design Guidelines

*- The development of design guidelines*

This chapter illustrated the general design guidelines and practical design recommendations for each harbour functional zones based on the questionnaire results from the previous chapter 3.2.3 and relevant literature in chapter 2.

The empirical research findings were analysed and integrated for the development of design guidelines. The closed-ended rankings (quantitative data) gives an overview of the contributions of different types of street greenery and establishes a basis for further interpretation of the evaluation. Subsequently the open-ended reasons (qualitative data) explains the reasons behind people's preferences and provides practical design advices for each functional zone in harbour contexts.

## 4.1 General Design Guidelines

The sum points of the different greenery types were calculated (Table 3.5) and visualised (Figure 3.12) in each of the four harbour functional zones. The results show that in the port-industrial area and on residential waterfront the combination of *'trees'* and *'ground and low-height vegetation'* was slightly preferred among the other greenery types; whilst in the new business area and residential neighbourhoods the combination of *'trees'* and *'wall vegetation'* was more favoured by people.

This findings can be used as a basis to combine different types of street greenery in the planning and design process, and adapted to different contexts according to the site-specific conditions and spatial characteristics.

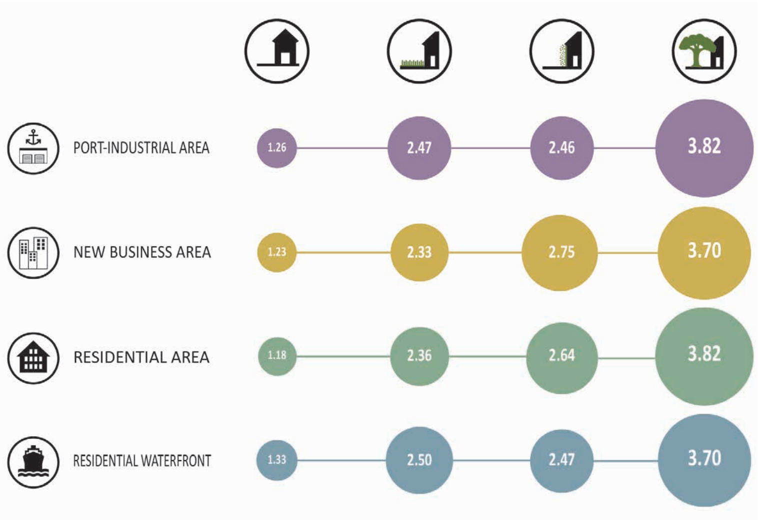



Figure 4.1 Sum points of the different greenery types in each of the four harbour functional zones. The number refers to the mean points by using a scale range from 1 to 4, which 4 is the highest point; the size of the dots approximates the total of the points

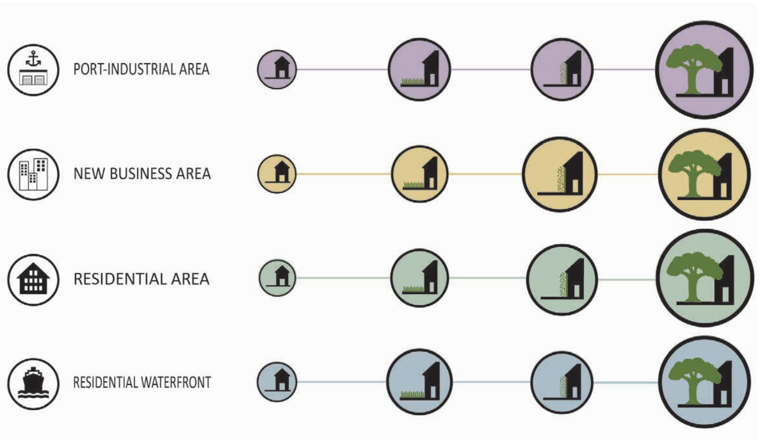



Figure 4.2 Visualisation of the general design guidelines; the size of the dots approximates the total of the points

| sRQ 1 (What) | | sRQ 2 & 3 & DQ 1 (What & How) |
|---|---|---|
| Functional zone | **Spatial Characteristics** | **Design Guidelines & Recommendations** |
| **Port-industrial** | ▪ Surrounded by heavy traffic roads and the pavement for transportation purpose<br>▪ Low-rise buildings and container buildings<br>▪ Visible harbour elements (e.g. crane, smokestack) | ▪ Using trees to mask unpleasant industrial scenes and combined with ground and low-height vegetation to increase visibility of greenery for improving perceived thermal comfort<br>▪ Placing the greenery while keep the harbour functioning. For example, replacing the traditional pavements in parking lots and low-traffic roads with permeable grass pavers which helps to mitigate the high surface temperature of the port-industrial area without taking up space, and at the same time make the street looks greener.<br>▪ Integrating greenery into the existing building structures (e.g. covering the bare walls, fences or container buildings with wall vegetation) to shape the harbour landscape with a wild and natural look (e.g. combining the vegetation design with materials shows harbour character such as CorTen steel).<br>▪ Low maintenance greenery planning.<br>▪ Too much green decoration is unnecessary in such a working area. |
| **New business** | ▪ Mixed-use building typologies (i.e. a mixture of high-rise office buildings and the monuments)<br>▪ Streets with buildings of varied heights (asymmetrical canyon)<br>▪ A variety of street widths<br>▪ Roadside parking | ▪ Greening the building façades with wall vegetation that fits the surroundings. In this way, the vegetation surface have screening effect to block the direct sunlight and thus positively affect both indoor and outdoor thermal conditions; also it contributes air filtration for fresh air supply at street level. Meanwhile, wall vegetation is considered as the most suitable green elements to shape the atmosphere in business areas that attracts people, especially workers.<br>▪ Using trees to create shaded areas for people's outdoor activities as well as for car parking as a shelter from direct sunlight; but not cover too much of the surroundings as people prefer to have a clear overview of the street which provides sufficient information for them to recognise the place.<br>▪ Using greenery as indicator to enhance route planning and accessibility of the outdoor spaces between buildings. |
| **Residential** | ▪ Residential buildings on both sides of the street<br>▪ Parking lots in front of the houses<br>▪ Neighbourhoods with harbour views | ▪ Planting large trees to provide shelter from different weather conditions (i.e. sun, wind, rain) and at the same time enhance ecological services (e.g. bird habitat).<br>▪ Diversifying the neighbourhood by using a wide range of plant species. For example, choosing deciduous trees that shows leaf colour changes combined with flowers beneath trees to enrich the aesthetic quality and people's perception of the living areas.<br>▪ Considering the greenery planning when design the houses (e.g. design the balcony which is suitable for planting etc.) |
| **Residential Waterfront** | ▪ Residential buildings with a view to the water<br>▪ Open waterfront with harbour views | ▪ Using vegetation ground covers (e.g. grass) to provide spaces for outdoor activities and create inviting atmosphere.<br>▪ Greening the waterfront with ground and low-height vegetation to create soft edge with the pavements and beautifying the spaces. In this way, the presence of greenery are in people's visual field and therefore lead to a better thermal perception as well as aesthetic appreciation.<br>▪ Choosing smaller trees or positioning the trees specifically to avoid obstructing the view, both at street level and from the windows of the residential buildings next to the waterfront. |

Table 4.1 Design guidelines and recommendations for the four functional zones in harbour contexts

## 4.2 Design Guidelines and Recommendations for the Four Harbour Functional Zones

Four functional zones in harbour contexts (port-industrial; new business; residential; residential waterfront) were identified with different spatial characteristics. For each of them different planning and design guidelines for improving perceived thermal comfort and attractiveness are shown in Table 4.1.

In addition to responding to different spatial characteristics of each functional zones, some general planning and design guidelines on greening were summarised as follows:

- Preserving the existing green areas and on-site green elements, extending the green volumes and adding diversity based on the original vegetation structure.

- Using local plant species which fits to the climatic characteristics.

- In general, broad streets are often found in a former harbour area due to previous use of port activities and transportation. For improving perceived thermal comfort and attractiveness in wider canyons, it is important to focus on the presence of vegetation in people's visual field, by using different greenery types with various physical features (i.e. vertical, horizontal, 3D objects) to increase the visibility of street greenery.

- Checking underground infrastructure in order to ensure the possibility for healthy plant growth. The underground infrastructure systems are generally more complex in new business and residential areas in response to energy supply and demand.

Photo credit: Christy Tang. (2014).

# 5
# Case Study
## Merwe-Vierhavens, Rotterdam

## 5.1 Background Analysis

### *5.1.1 A brief overview of port-city developments in Rotterdam*

Rotterdam recovered rapidly after World War II and the city is undergoing constant change. The actual redevelopment of urban waterfront in Rotterdam started in 1980s, basically can be divided into two stages.

The first stage began since the municipality of Rotterdam launched a large scale waterfront regeneration project named Kop van Zuid (KvZ), which can be translated as Southern Headland. The project area is a peninsula located on the south bank of the river Nieuwe Maas, where used to function as a working dock with shipyards. However, all the port activities were ultimately shut down when the port moved west to the mouth of the river during the 1960s and 1970s. As a result, this area was abandoned and became the breeding ground for social problems and had a poor image because of the low educational achievement and high unemployment rates, which made this area unattractive to private investment and those people who with choice to settle down.

In consequence, the project of Kop van Zuid aims to transform the derelict port sites into a lively mixed-use area by building up physical connection between port and city and bridging the psychological gap in order to reverse the image of the city for business investors and young potentials as well as to enhance local identity for residents.

After the success in the first stage of waterfront revitalization, the second stage started in 2002. The Stadshavens project, as a large scale urbanization plan, initially targeted the same strategy as Kop van Zuid with great ambition. However, the city and port authorities and decision makers realised that it is not comparable and infeasible to tackle this two cases in the same way. The reason is that the fundamentally different locations, Kop van Zuid is in the vicinity of the city centre, whilst Stadshavens area is on the periphery of the city. Also, the outbreak of the economic crisis made this ambitious plan unavailable. Consequently, an alternative strategy was formulated and approved in 2007.

The new strategy tends to approach the development by using small interventions aim at specific area and providing countermeasures to deal with the local dynamics. Unlike Kop van Zuid, the majority of the ports in Stadshavens area will keep working before the port activities being relocated to other places and gradually being taken over by urban functions such as residential districts, office buildings and recreational public spaces.

Therefore, the port's economy still plays a role for this stage of the waterfront development and needs to be taken into account. A bottom-up process of change is expected and the municipality and the port authority attempts to develop the port as well as the city in a harmonic way, so called *'organic development'* that several adaptive plans are employed to cope with the future uncertainties and the transformation process will take place by evolving a symbiotic relationship between port and city.

In short, Stadshavens put emphasis on the alliance between port and city and aims not only to exploit the financial potential for port activities with add values for the surrounding areas, but also to transform the area into a desirable living and working environment.

The port-city development and the evolution of port-city relations were summarised in chronological sequence, as shown in Table 5.1.

### *5.1.2 The project 'Stadshavens Rotterdam'*

Stadshavens, literally translated as city ports, is an area located in the peripheral suburbs of the city of Rotterdam, which covering 1600 hectares of land and water consisting of four harbour sites: Rijn-Maashaven, Waal-Eemhaven, RDM-Heijplaat, and Merwe-Vierhavens (Figure 5.1).

Each area has different focuses for the redevelopment according to context and spatial characteristic. The Stadshavens area of Rotterdam is the conjunction area between the city and the port, the four active harbour sites within this area are the only ones still situated inside Rotterdam's highway rim, providing jobs to more than 20,000 people. However, almost the entire area is currently surrounded by dikes, heavy rail infrastructure, and social-class neighbourhoods; many public spaces and buildings in this area are in poor condition or disused after the westward expansion of ports, which makes the area less attractive and in urgent need for improvement (Daamen & Vries, 2012).

| *Stage* | *Symbol*<br>● Port ○ City | *Period* | Remarks |
|---|---|---|---|
| **Before WWII** | | | |
| **(I) Primitive port/ city** | | 16th century | Close spatial and functional association between city and port |
| **(II) Port-city relation**<br>Waterstad: building integrated dike system | | 1600s onwards | Rotterdam water city development: prior to the 17th century, Rotterdam was situated entirely within its dike system |
| Boompjes: green urban waterfront | | 1615 | Represented the city's definitive 'leap' over the dikes: the spatial and functional combination of city and port |
| Waterstad land expansion | | Late 1700s – early 1800s | Building new land outside the dike for port-related functions |
| The completion of the Nieuwe Waterweg | | 1872 | Enhanced the huge growth of Rotterdam and established the advantage of the port for future expansion |
| Bombing | | 14 May 1940 | Destroyed most of the historic city centre |
| **Post-war Reconstruction** | | | |
| **(III) Modern industrial port/ city** | | 1945 onwards | The industrialization trends started in 19th century: the recovering of Rotterdam after war and its industrial development. |
| Watersnoodramp<br>North Sea flood of 1953 | | 1953 | The policy of water management has changed. |
| **(IV) Expanding port/ city** towards the North Sea: westward movement of port development | | 1960s | The relocation of port activities to the west guided by industrial expansion and economic logics led to the geographical separation between port and city. |
| **(V) Retreat from the waterfront:**<br>Port regionalization | | 1970s – 1990s | Port and port system development on a higher geographical scale.<br>Functional interdependency network. |
| **(VI) Redevelopment of waterfront:**<br>1st wave of waterfront redevelopment: Kop van Zuid | | 1980s onwards | Large scale urban waterfront regeneration and transformation project of a disused port area.<br>Brining the river Maas back into the DNA of the city of Rotterdam and to make connection between the north and the south riverbanks. |
| **(VII) Renewal of port/ city links:**<br>2nd wave of waterfront redevelopment: Stadshavens | | Started in 2002 | Globalisation and intermodalism transform port roles and its interaction with the city. Urban redevelopment enhances port-city integration. |
| **(VIII) Port-city symbiosis:**<br>Harbor transformation and urban waterfront revitalization | | The present + | Green elements as the medium to create a symbiotic port-city relationship. |

Table 5.1 Port-city evolution timeline in Rotterdam. Inspired by Hoyle, 1989.


Figure 5.1 Location of the main harbour sites within Stadshavens area in Rotterdam (Gemeente Rotterdam, 2011)

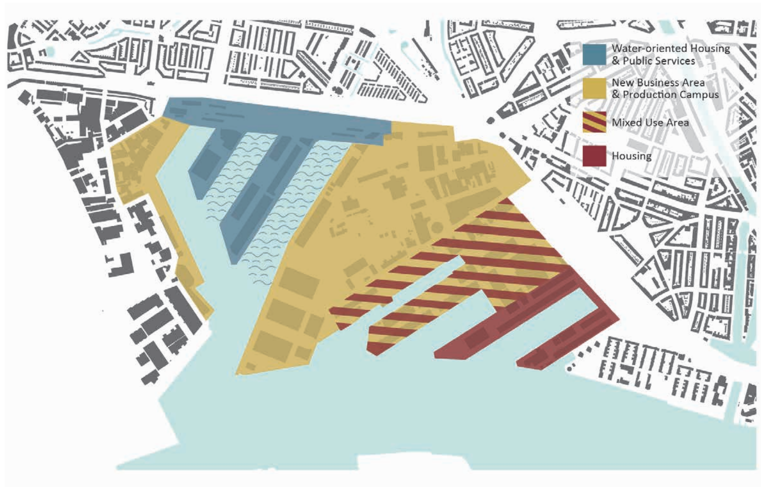



Figure 5.2 Development scenario and zoning plan for Merwe-Vierhavens. According to Gemeente Rotterdam, 2011

Hence, the objective of this project is to improve social, economic, and environmental conditions of the area by developing high quality living and working environment that directly links to education and the local labour market and adapts to climate change.

### *5.1.3 Site selection: Merwe-Vierhavens (M4H), Rotterdam*

The redevelopment of Merwe-Vierhavens (M4H) is an ongoing project launched by the municipality of Rotterdam and Rotterdam Port Authority under the major project Stadshavens Rotterdam.

Merwe-Vierhavens is the only area located in the north bank of the river Nieuwe Maas that neighbours with the city centre, which means the area has a better accessibility as an ideal living and working location.

According to Rotterdam's city vision on M4H, the area will transform into a mixed-use area that supports high-skilled economy with housing-friendly companies and creates an attractive water-oriented living environment with 4500-6500 homes to attract people (Figure 5.2).

By developing M4H, the surrounding areas are expected to benefit from the new opportunities offered by M4H development and encourage local growth. Apart from that, the municipality and the port authority has the ambition to make Merwe-Vierhavens functions as an international experimental site for testing and demonstrating innovative production industry and knowledge business in the field of Clean Tech (i.e. energy supplies and water management) (Gemeente Rotterdam, 2011; Gemeente Rotterdam & Havenbedrijf Rotterdam, 2009).

However, the current situation of the area is unattractive to people as a living environment due to the function-oriented development. Almost the whole area is surrounded by industrial roads mainly for transportation purpose and with a general lack of street greenery, which makes a greyish streetscapes of the area. Besides, M4H is located in the area with the highest surface temperature within the city of Rotterdam, which is an indicator of experienced heat and considering its built features, we can safely assume that the area has a poor thermal condition and suffered from urban heat problems.

To sum up, Merwe-Vierhavens has high potentials and opportunities for improvement in terms of thermal comfort and attractiveness. This area is facing the same problems and has the similar circumstances to many other port cities around the world, which means it is possible to enlarge the applicability of the research outcomes. Also, it is an ongoing project launched by the municipality of Rotterdam and Rotterdam Port Authority, which makes this research more practical and connect to the real world. Therefore, Merwe-Vierhavens is selected as the case study area for the present study.

## 5.2 Site Analysis

### *5.2.1 Heat stress*

It is observed that urban heat islands are often emerged in highly urbanised cities like Rotterdam resulted from the constantly evolving process of post-war reconstruction and urban developments. Anthropogenic heat produced by human activity contributes to the warming effect in the urban area. In Rotterdam, a relatively high surface temperature in the city centre (29°C) was observed, and the hottest spot is emerged at Nieuw Mathenesse (33°C), where the city and the port meet within Stadshavens area (Figure 5.3).

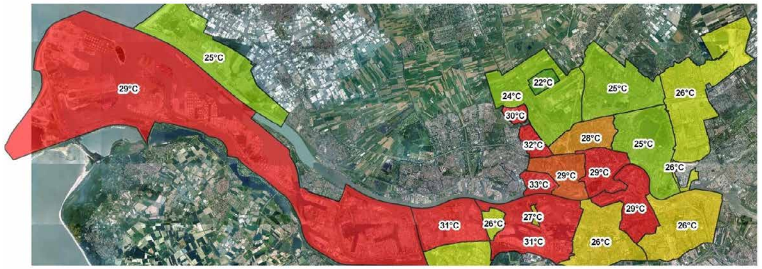



Figure 5.3 Average surface temperature of Rotterdam based on 15 Landsat images (Klok et al., 2009)

It must be noted that the measured surface temperature on urban boundary layer is not equal to people’s thermal perception. However, it could be an indicator suggest that the area is vulnerable to extreme heat and possibly contribute to thermal discomfort. According to the measurements conducted in Rotterdam, a relatively high physiological equivalent temperature (PET) was observed in the industrial areas northwest of Rotterdam city, where M4H is situated. (Hove et al., 2011b).

### *5.2.2 Street types*

The analysis of four harbour functional zones were based on the zoning plan formulated by the municipality of Rotterdam (Figure 5.2). Each zone have different street geometry and spatial characteristics according to the current situation. The aspect ratio of each street is calculated and analysed, as shown in Figure 5.4. The result shows that the dimension of the streets in M4H are relatively broad and very often have an aspect ratio below 0.5, which can be defined as avenue canyon (Carmona, 2010; Ali-Toudert & Mayer, 2006).

This is mainly resulted from its harbour context and the transportation needs of the area.

However, wider canyon may lead to higher surface temperature due to larger surfaces exposure to the sun, but at the same time it has more spaces for outdoor activities. Therefore, the role of street greenery is significant in improving thermal comfort and attractiveness of the canyon. As Ali-Toudert & Mayer (2006) suggested that *"contemporary urban design must integrate motor traffic (i.e. wider streets) and a greater degree of activity to support social urban life"*. This means that the street design solutions should *"meet both comfort and usage needs"*. Besides, in a wider canyon, shading strategies and the thermal benefits of urban vegetation should be implemented directly at street level (e.g. grass ground covers, green walls, green façades, low plants and rows of trees etc.) (Ali-Toudert & Mayer, 2006).

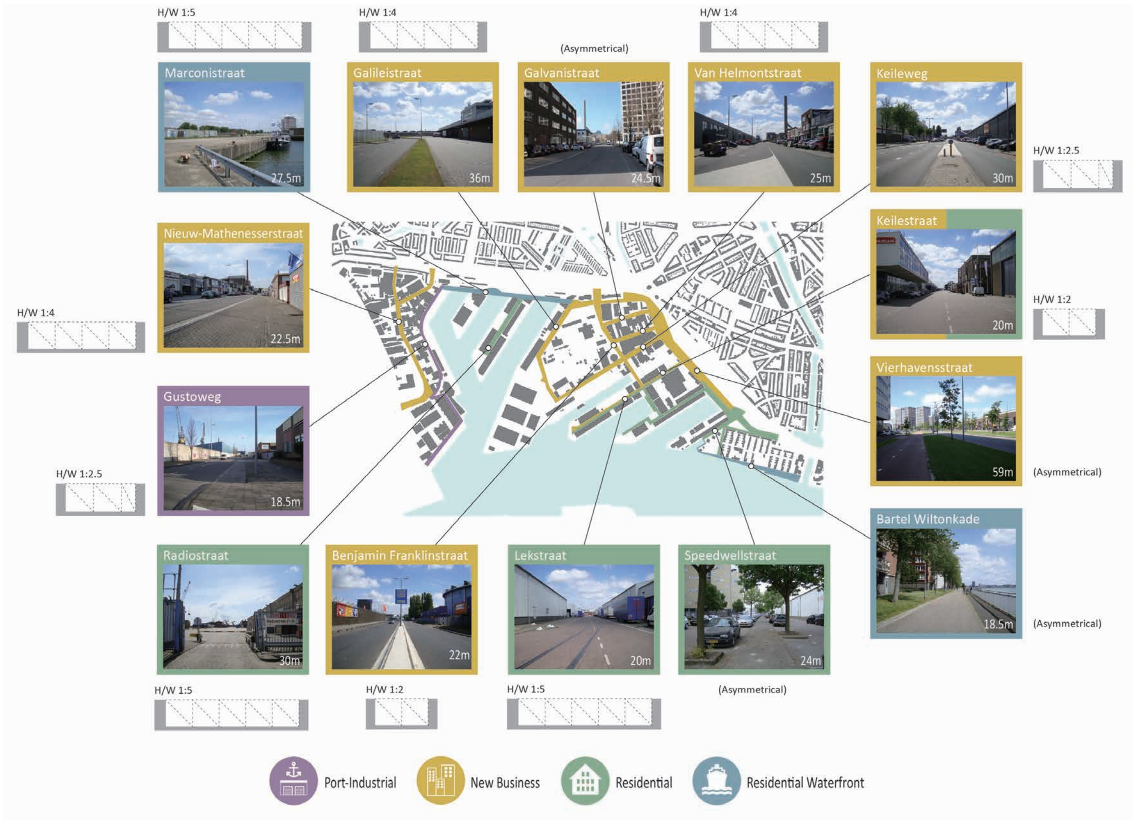



Figure 5.4 Street analysis according to harbour functional zones in M4H area

### *5.2.3 Green structure and typology of green spaces*

The local vegetation structure and the existing green areas consisted of different types of green elements in M4H were mapped. The implementation of design guidelines and the follow-up design of street greenery will be developed based on the original green structure.

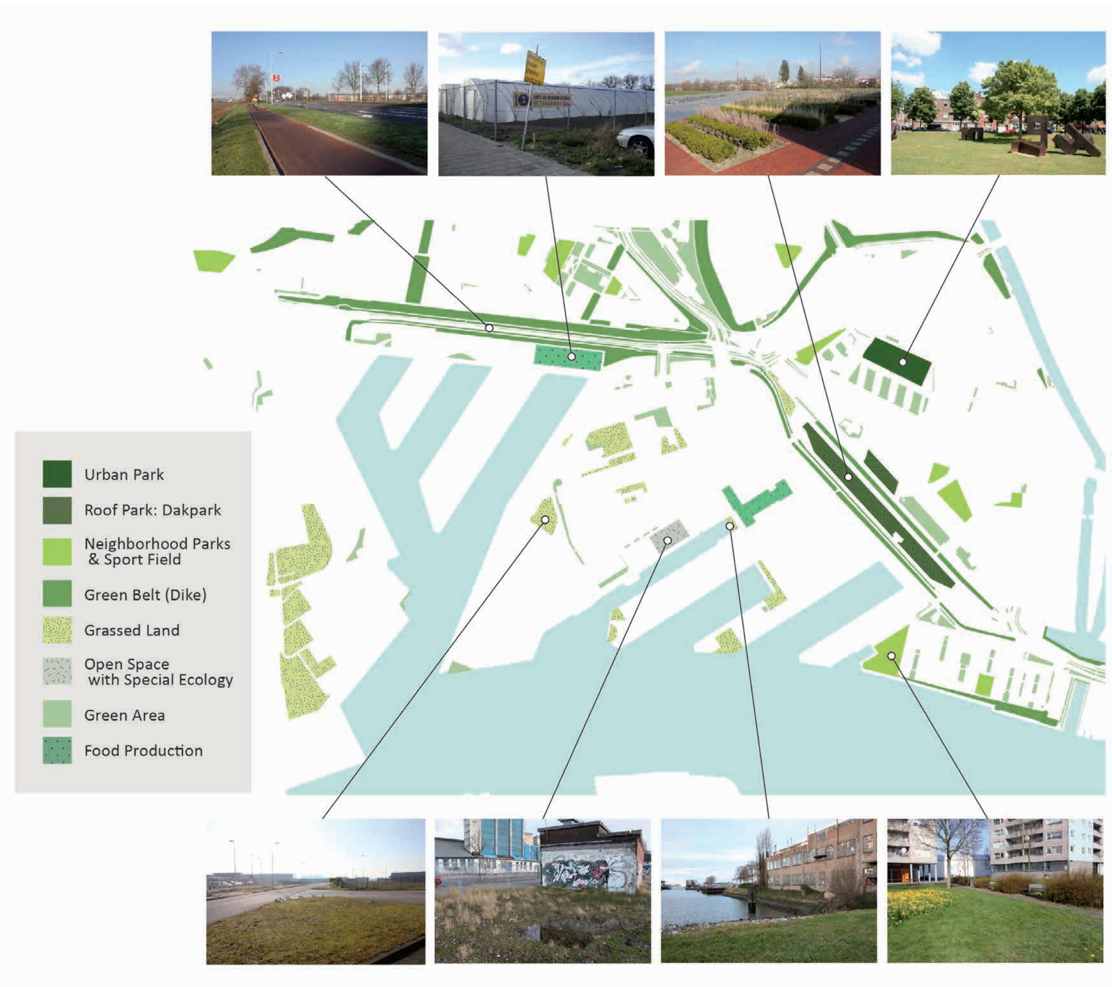



Figure 5.5 Existing green structure and the typology of green areas in M4H area

## 5.3 Implementation of Design Guidelines

The current situation of the spatial contexts in M4H area are presented, followed by the design for each functional zone and the reference images that represents different types of street greenery.

***Port-industrial Area***

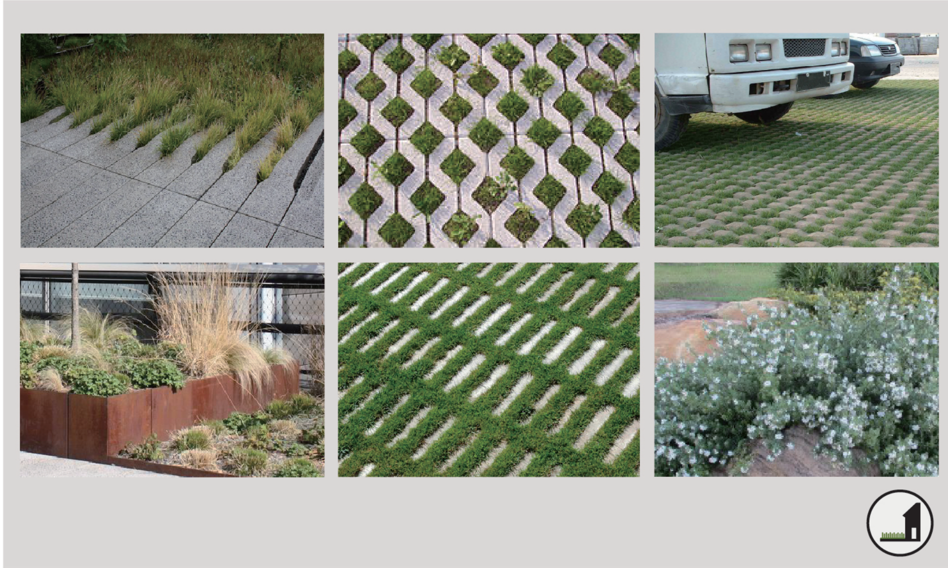
***New Business Area***

Photo credit: Christy Tang. (2014).

***Residential Area***

***Residential Waterfront***

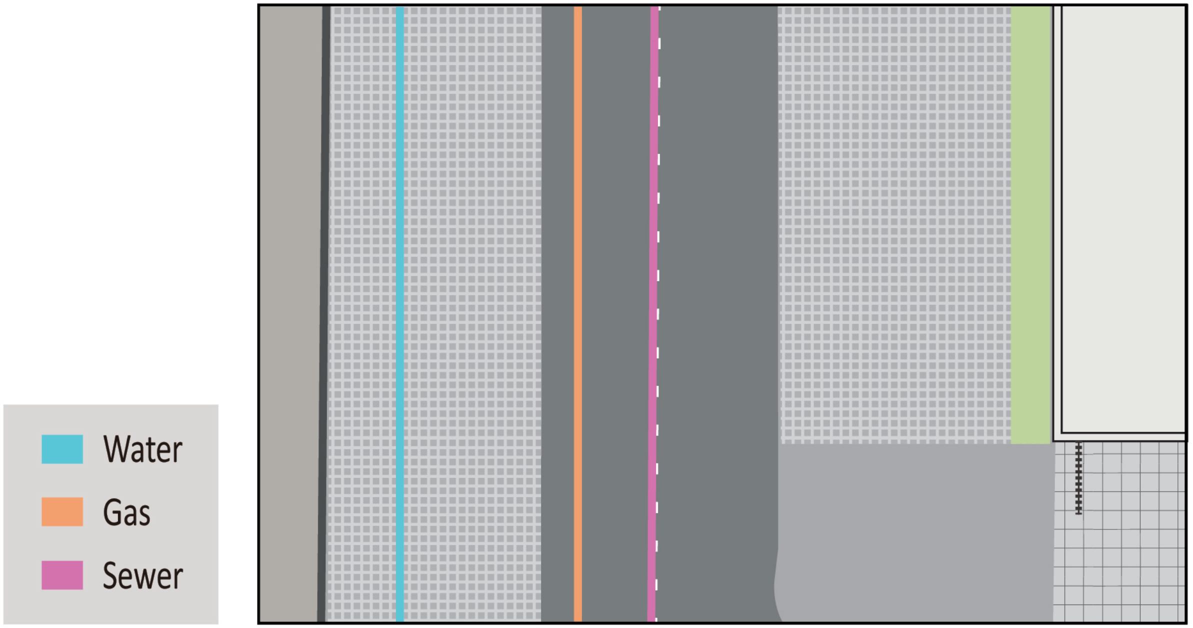
Photo credit: Christy Tang. (2014).



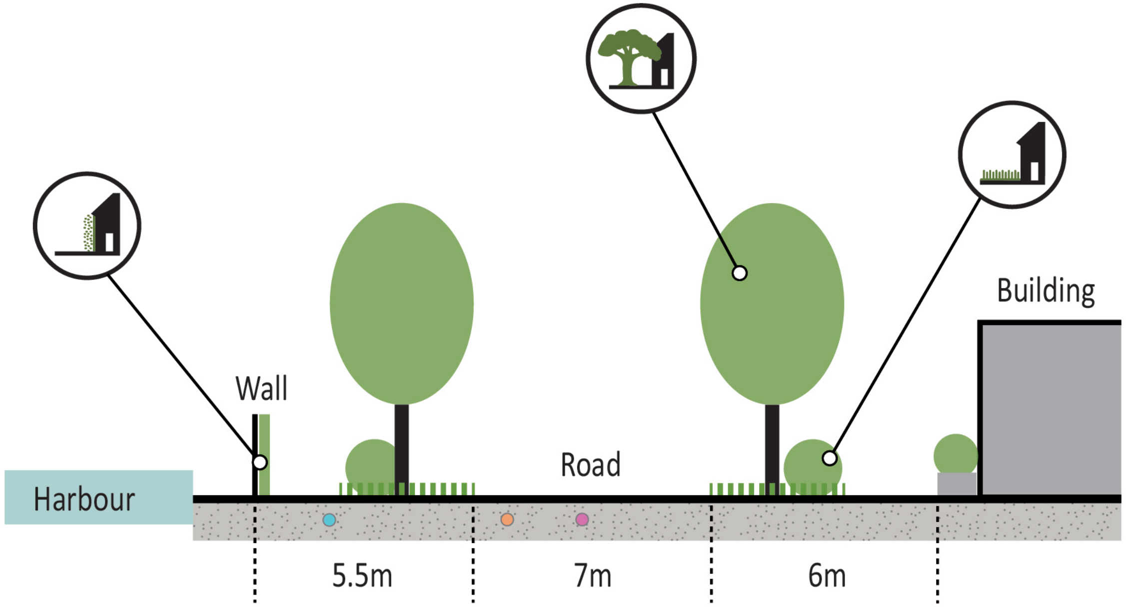
Keeping the existing roadside trees and using the same species of tree (i.e. **Ulmus x hollandica 'Dampieri'**) to function as natural buffer to visually obstruct incompatible industrial scenes.

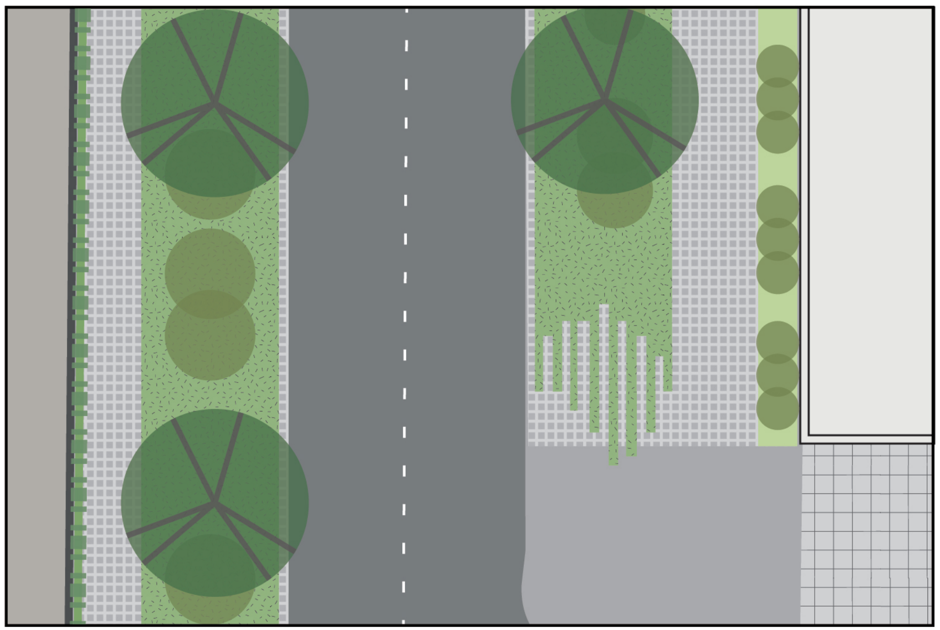
Combining the vegetation design with rough materials such as CorTen steels and gabions filled with rocks to shape the harbour character.

**Street Layout & Underground Infrastructure**

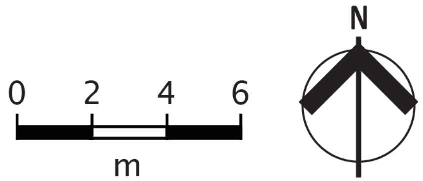


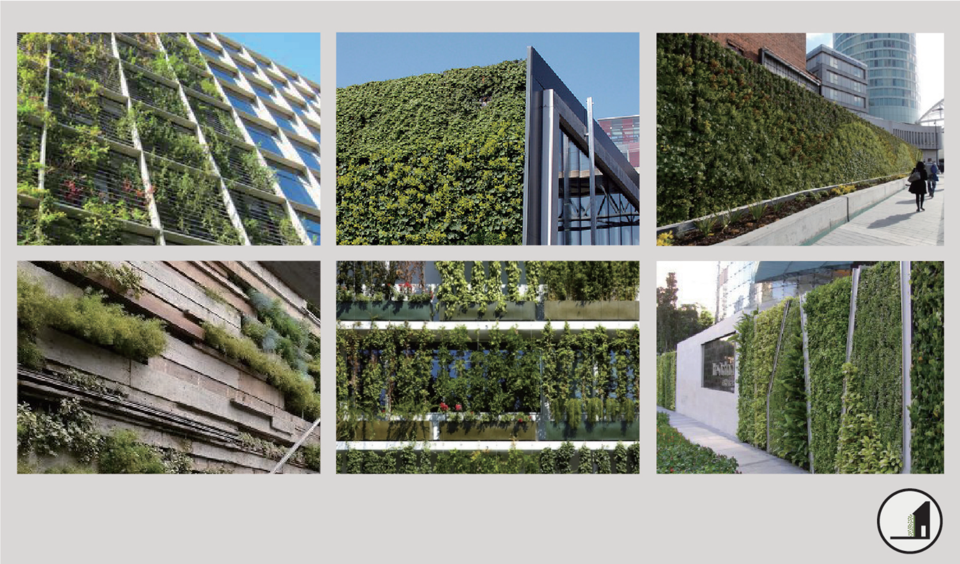
## Port-industrial Area

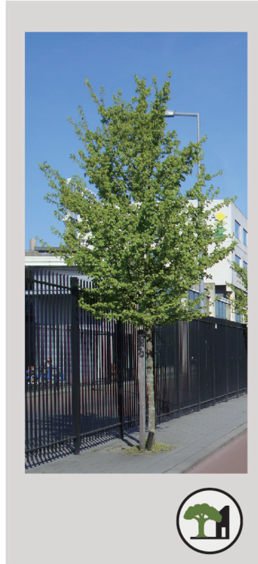


Replacing the paving materials in parking lots and low-traffic roads with different designs of the pavements combined with low maintenance ground vegetation (e.g. grass pavers). In this way, the street are visually greener at pedestrian level and in the meanwhile to ensure work efficiency associated with transportation in terms of accessibility and connectivity.

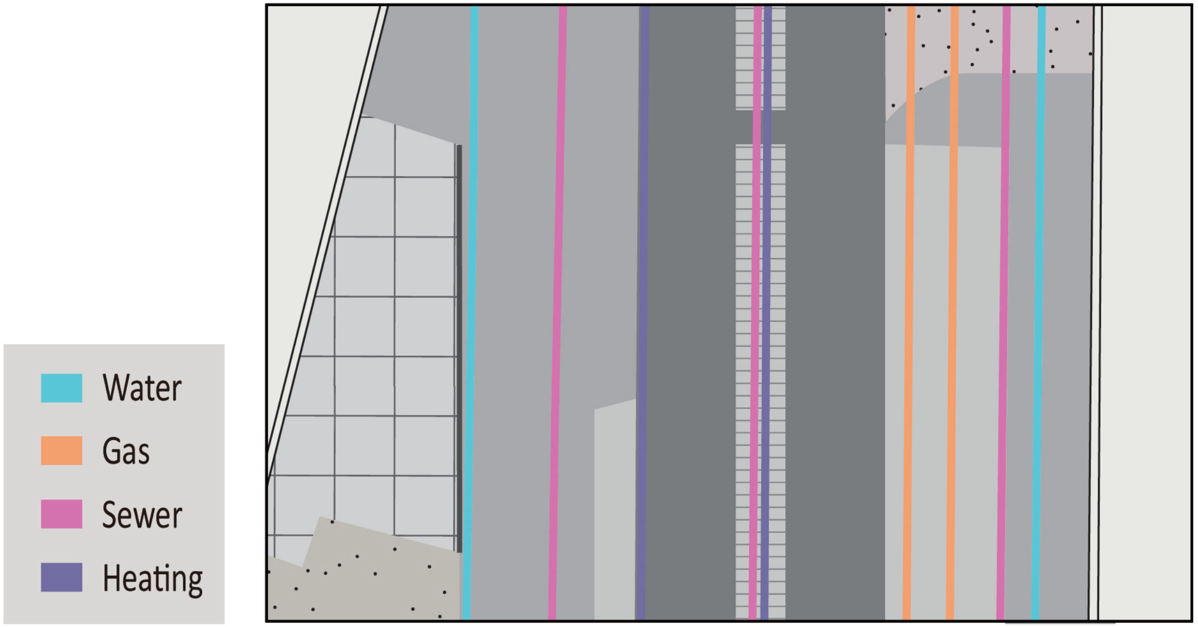


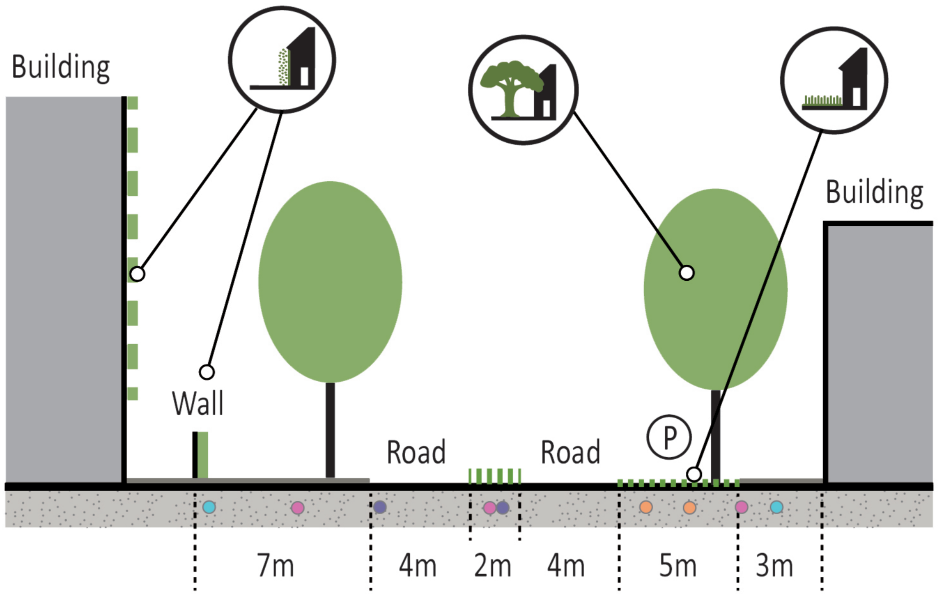


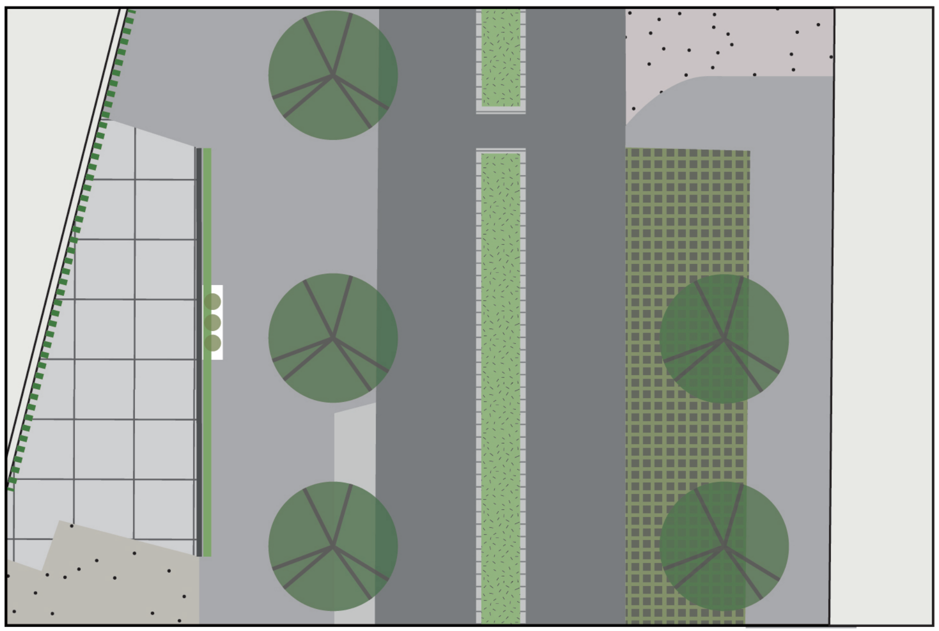


The underground infrastructure systems are generally more complex in business area due to the energy supply and demand for the companies and office buildings. In this case, planting beds can be applied on the sidewalk and combined with the design of street furniture that supports outdoor activities.

## Street Layout & Underground Infrastructure



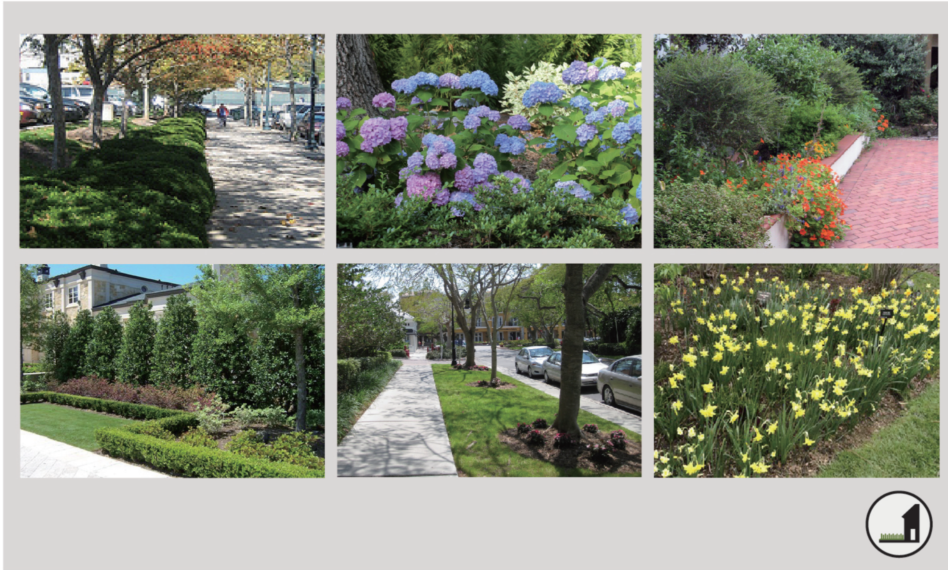


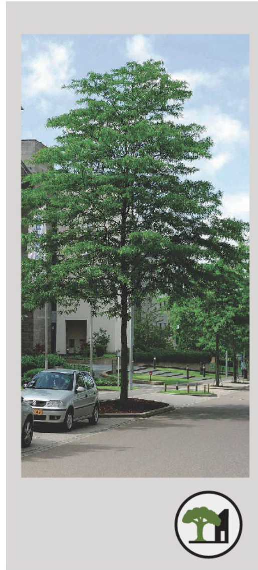



**New Business Area**

Adding the green traffic island in the middle of the road for extending the green volume at street level. This also helps to enhance traffic safety by providing pedestrian refuge and slowing the cars due to the width of the road has shrunk.

Greening the building façade with wall vegetation to increase the visibility of greenery and enhance aesthetic quality.

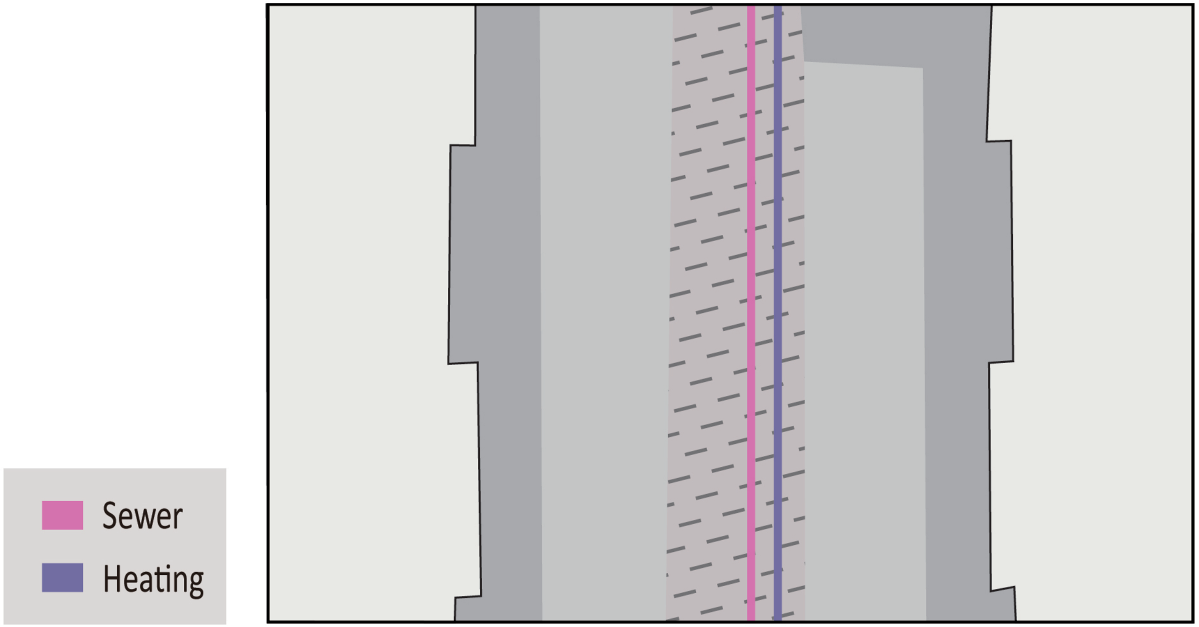


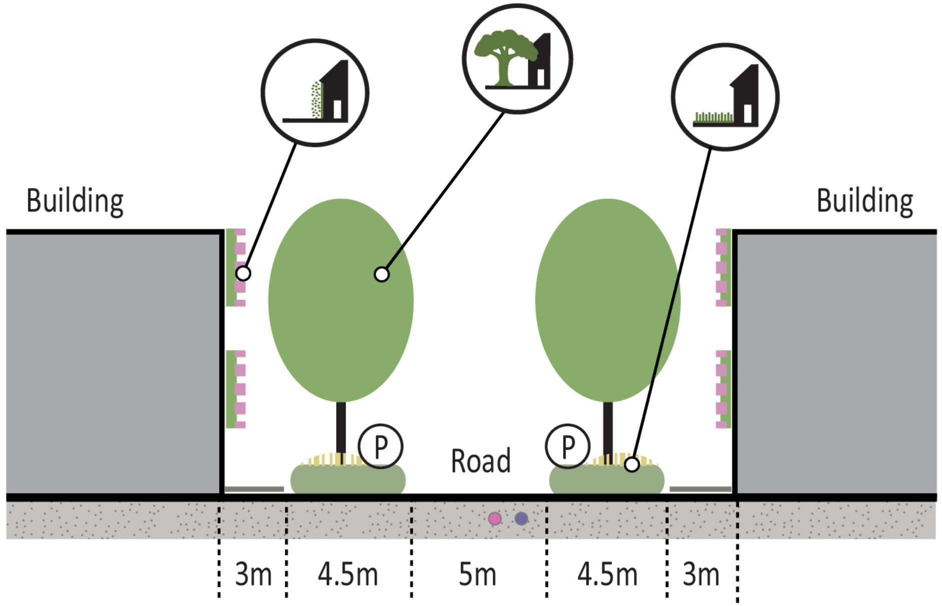


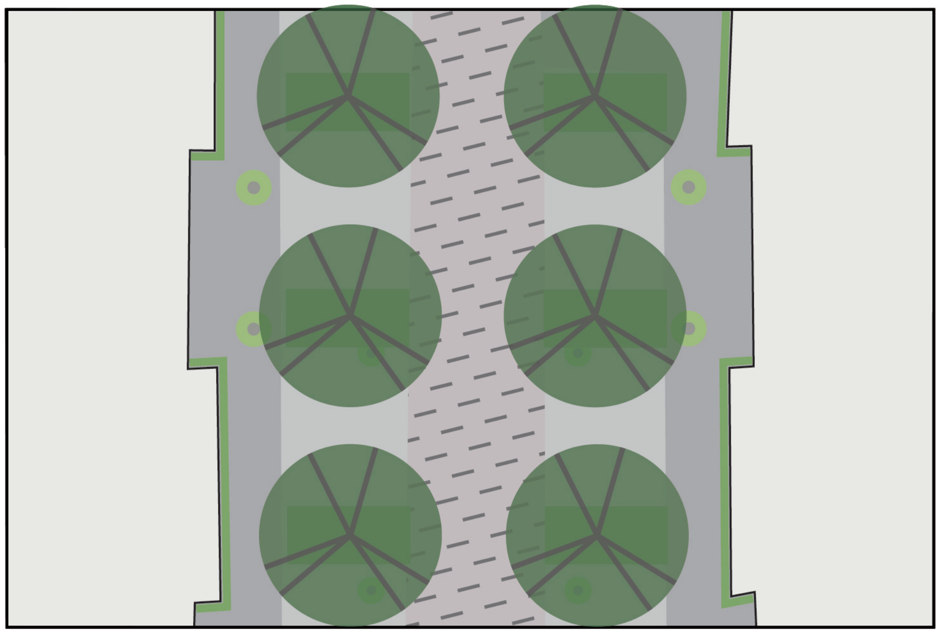
Using local tree species (i.e. **Gleditsia triacanthos 'Skyline'**). Furthermore, selecting slow-growing trees with a small root ball to keep the tree roots from the sewer lines.

Diversifying the neighbourhood by using various plant species that shows different colours (e.g. leaf colouring of deciduous trees, flowering trees or flowers etc.) and textures to enrich the aesthetic quality and people’s perception in their living environments.

### Street Layout & Underground Infrastructure



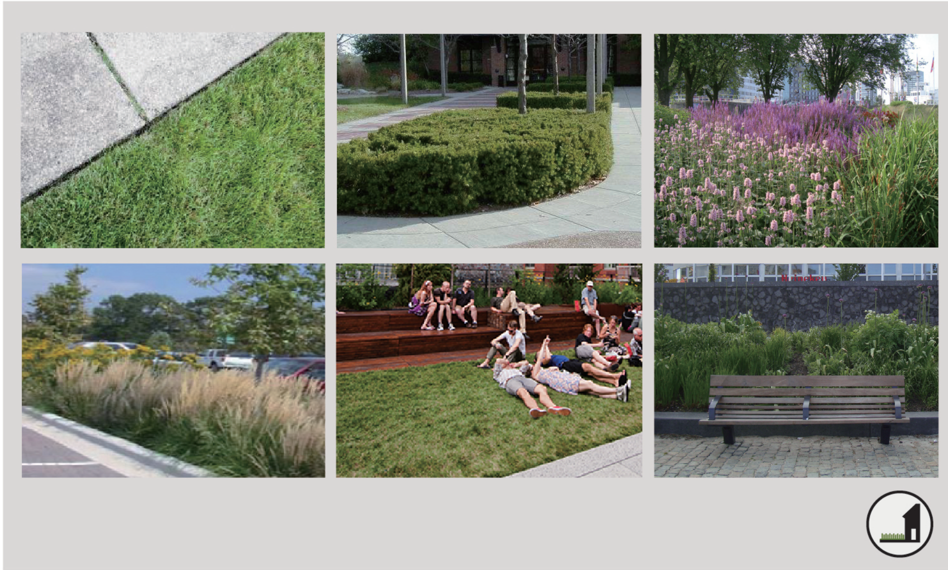


## Residential Area

Planting large trees in the residential street to shelter residents from different weather conditions (i.e. sun, wind, rain) and at the same time attract bird habitat that increases aesthetic quality of the neighbourhood.

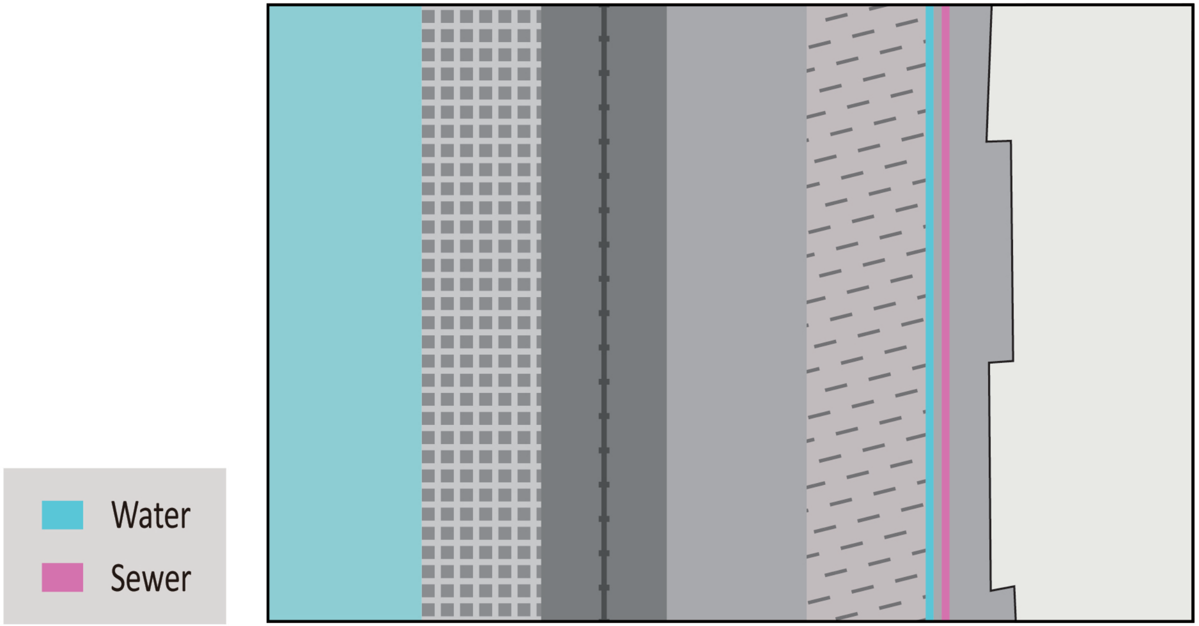
Using low plants beneath trees to create different layers of street greenery (i.e. plants with different heights) that contains more varied vegetation in people’s visual field.



Softening the edge of riverbank by using aquatic and water-friendly plants. This not only contributes to thermal comfort but also enhances the attractiveness of the waterfront.

Positioning the trees concerning the view and the need for shaded areas that supports various outdoor activities.

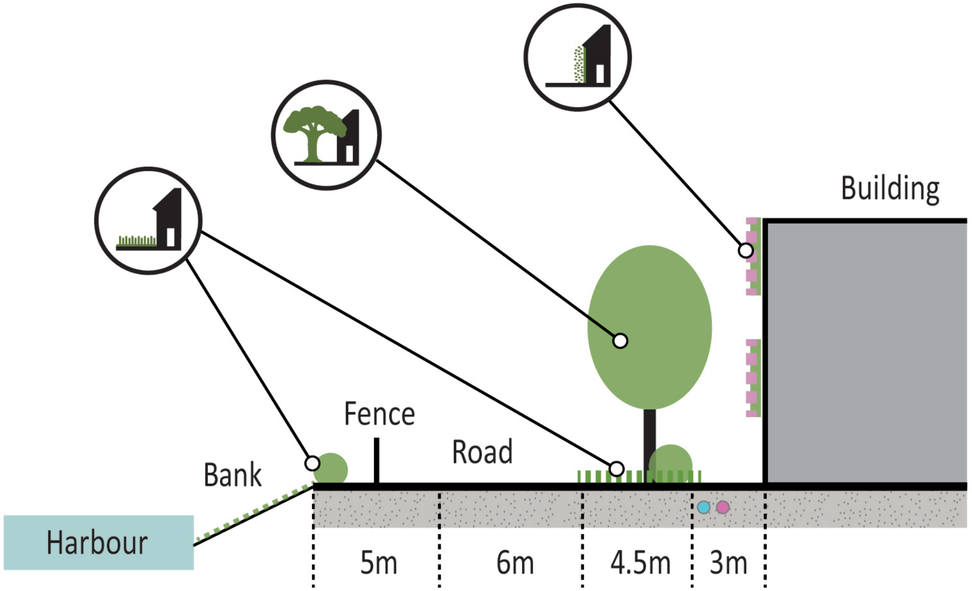
**Street Layout & Underground Infrastructure**

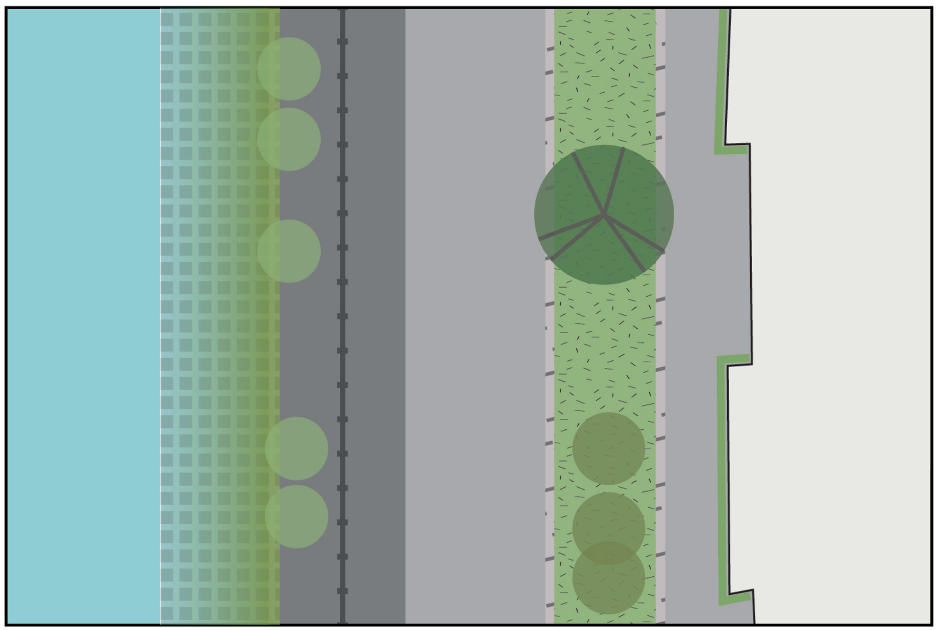


## Residential Waterfront







Using ground and low-height vegetation (e.g. grass, shrubs, hedges, small trees etc.) to design the streetscape that provides an open view and spatial experience of the water-front for user enjoyment.

Integrating the green elements into the design of street furniture such as benches and streetlamps.

# Reference


**A** Ali-Toudert, F., & Mayer, H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Building and Environment, 41, 2, 94-108.

**C** Carmona, M. (2010). Public places, urban spaces: the dimensions of urban design. Routledge.

**D** Daamen, T. A., & Vries, I. (2012). Governing the European port–city interface: institutional impacts on spatial projects between city and port. Journal of Transport Geography.

**G** Gemeente Rotterdam & Havenbedrijf Rotterdam (2009). Gebiedsplan Merwehaven-Vierhavens: Pionieren aan de Maas. Projectbureau Stadshavens Rotterdam. Available at: http://stadshavensrotterdam.nl/wp-content/uploads/2009/05/Merwe-Vierhavens8-def-4-2.pdf [Accessed at: 21-03-2014]

Gemeente Rotterdam (2011). Merwe-Vierhavens: Notitie Reikwijdte en detailniveau MER behorend bij het Bestemmingsplan. Projectbureau Stadshavens Rotterdam. Projectcode: 20110221.

**H** Hove, B. van, Jacobs, C. M. J., Heusinkveld, B. G., Elbers, J. A., Steeneveld, G. J., Moors, E.J., & Holtslag, A. A. M. (2011b). Exploring the urban heat island intensity of Dutch cities. In: Hebbert, M., Jankovic, V., Webb, B., & University of Manchester (Eds.) (2011). City weathers: Meteorology and urban design 1950-2010. Manchester Architecture Research Centre (MARC), 31-38.

**K** Klok, L., Zwart, S., Verhagen, H., & Mauri, E. (2009). The surface heat island of Rotterdam derived from satellite imagery. SENSE Symposium Climate Proofing Cities, Amsterdam & Volendam, 1 December 2009.

1 Tang, Christy. (2014)

2 Mike Davis/The OregonianHotel Modera's garden. Oregonlive.
Retrieved from http://www.oregonlive.com/hg/index.ssf/2009/06/urban_gardens_go_up_the_wall.html

3 Found on its-a-green-life.com pinned by Ekaterina Frank. Rebar planter holder. Pinterest.
Retrieved from https://www.pinterest.com/pin/391320655095243445/

4 Andy Beard. (2013). Gabion car park cladding. Gabion.
Retrieved from http://www.gabionbaskets.co.uk/blog/item/gabion-car-park-cladding

5 Phillip Merritt. (2009). High Line Park. HiG: how it grows.
Retrieved from http://www.howitgrows.com/2009/08/high-line-park.html

6 Immanuel Giel. (2007). Pavement. Wikimedia Commons.
Retrieved from http://commons.wikimedia.org/wiki/File:Rasenpflasterstein_1.jpg

7 Grass Paving Blocks. LVFAR Kin Fung Green Reusable Industry Limited.
Retrieved from http://www.lvfarkf.com/en/product-Grass-planting-Brick.html

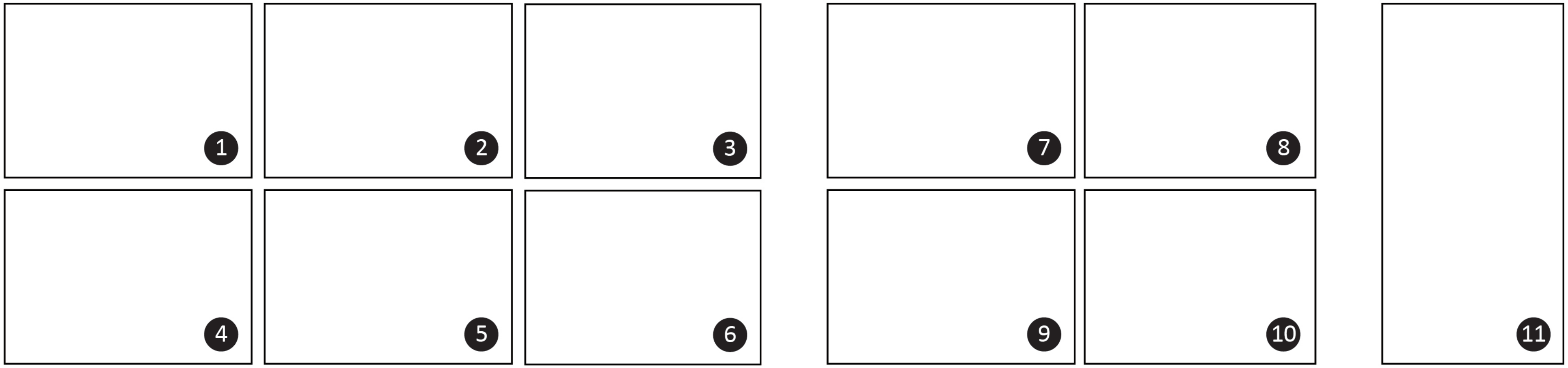
8 Alice Webb. (2012). Cor-Ten steel planters. Land Perspectives.
Retrieved from http://landperspectives.com/category/plants-2/page/2/

9 REDES paving system designed by Alfredo Arribas. Escofet.
Retrieved from http://www.escofet.com/pages/productos/ficha_productos.aspx?IdP=121&FA=

10 Westringia Mundi™ plant. Environmental turf and landscape gardening plants breeder. Ozbreed.
Retrieved from http://selector.com/nz/products/westringia-mundi-plant#img1

11 Ronnie Nijboer. (2006). RN Ulmus Columella (koninginneweg amsterdam). Wikipedia.
Retrieved from http://en.wikipedia.org/wiki/Ulmus_'Columella'#/media/File:RN_Ulmus_Columella_(koninginneweg_amsterdam).jpg

## New Business Area




1. Pasona Tokyo Headquarters by Kono Designs. Pictures.dot.news.
Retrieved from http://picturesdotnews.com/2014/05/01/8-delicious-examples-of-architecture-farming-photos/

2. Nicolas Nova. (2009). Green façade. flickr.
Retrieved from https://www.flickr.com/photos/nnova/3557022388/

3. Exterior landscaping in front gardens & city streets reduces pollution. Office landscapes.
Retrieved from http://officelandscapes.co.uk/blog/exterior-landscaping-in-front-gardens-and-city-streets-reduces-air-pollution/

4. Found on blog.dotandbo.com pinned by Beth Allison. Wood and plant wall. Pinterest.
Retrieved from https://www.pinterest.com/pin/396387204673789712/

5. Green façade: MMA Architectural Systems. Buildingpieces.
Retrieved from http://www.buildingpieces.com/products-info/groupIds/22/productId/680/subCatId/59/catId/0

6. Living Walls at the entrance of a high valuable Condominio in Singapore, November 2010. World Green Infrastructure Network.
Retrieved from http://www.worldgreenroof.org/Photos-Images-Green-walls-archive-2011.html

7. ECORASTER permeable paving  as storage space for cars – Parking Lohengrin Therme. Green way pavements.
Retrieved from http://greenwaypavements.com/ecoraster-permeable-pavingas-storagespace-for-cars/

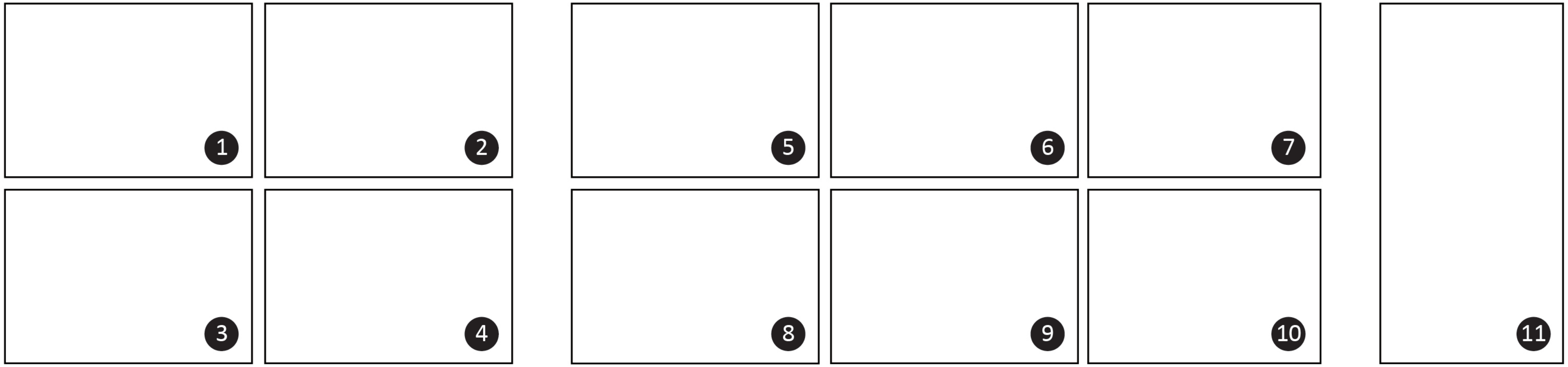
8. Vulcapark. Green car parking areas. Europomice.
Retrieved from http://www.europomice.com/products/volcanic-mixtures/vulcapark/

9. Buxus. The garden hedge.
Retrieved from http://www.gardenhedge.com.au/box-hedge/

10. Green Bricks. Pith + Vigor.
Retrieved from http://www.pithandvigor.com/shop-for-garden-products/accessories/new-products-green-bricks-a-modern-bbq-pretty-pots/

11. Tang, Christy. (2014).

1. Found on spaceforinspiration.blogspot.com pinned by Francine Richter. Amsterdam. Pinterest. Retrieved from https://www.pinterest.com/pin/166985098654284468/
2. Patrick Blanc cited by Simona Ganea. Amazing vertical gardens around the world. Homedit. Retrieved from http://www.homedit.com/amazing-vertical-gardens-around-the-world/
3. Heather Inde. Making Your Balcony Awesome. Heather goes to Deutschland. Retrieved from https://heathergoesdeutsch.wordpress.com/2012/05/27/making-your-balcony-awesome/
4. Ham. (2011). London daily photo: flowers in the street. Blogger. Retrieved from http://londondailyphoto.blogspot.nl/2011_08_01_archive.html
5. DEP Montgomery County, MD. (2011). Shaded sidewalk. flickr. Retrieved from https://www.flickr.com/photos/mocobio/11422980564/in/album-72157637844941874/
6. Kate. (2013). What's Blooming: June 2013. Gardening and gardens. Blogger. Retrieved from http://gardeningandgardens.blogspot.nl/2013/06/whats-blooming-june-2013.html
7. Raised Bed Gardening. Hillsborough extension garden blog. Retrieved from https://hcgreenthumb.wordpress.com/2010/12/
8. Plant a private screen. Landscaping network. Retrieved from http://www.landscapingnetwork.com/landscaping-ideas/privacy/screen.html
9. James Dougherty. (2013). Curbside Parking Footways in Downtown Naples, FL. Towncrafting. Blogger. Retrieved from http://towncrafting.blogspot.nl/2013_04_01_archive.html
10. Panayoti Kelaidis. (2012). Daffodils under shrubs and trees. Denver botanic gardens. Retrieved from http://www.botanicgardens.org/blog/its-springtime-yippeeeee
11. GLEDITSIA triacanthos 'Skyline'. Bruns. Retrieved from http://web03.bruns.de/bruns/en/EUR//Pflanzen/GLEDITSIA-triacanthos-'Skyline'/p/1150




1. Canaris. Grass stripes, raw. Dreamstime.
Retrieved from http://www.dreamstime.com/stock-image-grass-stripes-raw-image19728721
2. Tang, Christy. (2014).
3. Tang, Christy. (2014).
4. Green façade: MMA Architectural Systems.
Retrieved from http://www.buildingpieces.com/products-info/groupIds/22/productId/680/subCatId/59/catId/0
5. Trim-Free Landscape Edging. (Photo credits: Jupiterimages/Creatas/Getty Images cited by Jessica Kolifrath). Home guides.
Retrieved from http://homeguides.sfgate.com/trimfree-landscape-edging-57763.html
6. Short hedges: talltreesgroup.com. GetDomainVids.
Retrieved from http://www.getdomainvids.com/keyword/short%20hedges/
7. Tang, Christy. (2013).
8. Green parking at FDR state park. Nature times.
Retrieved from http://nysparksnaturetimes.com/2014/07/29/green-parking-at-fdr-state-park/
9. Navid Baraty. (2013). 23rd Street Lawn re-opens for the season. Friends of the High Line.
Retrieved from http://www.thehighline.org/blog/2013/05/18/23rd-street-lawn-re-opens-for-the-season
10. Tang, Christy. (2013).
11. Tang, Christy. (2013).

Photo credit: Christy Tang. (2014).

# 6 Conclusion & Recommendations

## 6.1 Conclusion

For answering the global issues associated with climate change and post-industrial urban development in contemporary world port cities. This thesis proposes a set of design guidelines for thermally comfortable and attractive streetscapes in harbour contexts based on people's perception of different greenery types. The results of this thesis support landscape architects and urban planners to plan suitable types of street greenery within various harbour functional zones. The former harbour sites can be converted into new living and working environments with thermally comfortable and attractive streetscapes by applying the generated design guidelines. That way, this thesis contributes to the process of harbour redevelopments and post-industrial urban plans to develop climate-adaptive and more liveable urban environments in growing cities.

In the present study, literature review and questionnaire survey were applied to investigate the impacts of different types of street greenery on people's long-term thermal perception and aesthetic appreciation. The questionnaire study in the form of online and face-to-face surveys were conducted in the city of Rotterdam, the Netherlands, in 2014. This investigation focuses on four alternatives of greenery types (no vegetation, ground and low-height vegetation, wall vegetation, trees) within different harbour functional zones on warm summer days and answered the following research questions:

**What design guidelines for thermally comfortable and attractive streetscapes in harbour areas can be generated based on people's perception of street greenery?**

*[sRQ1] What are the different functions and typical urban typologies applied to harbour redevelopment projects and in post-industrial urban plans?*
First, four different functional zones in harbour contexts were identified by literature review (see chapter 2.1.2) and on the basis of municipal zoning plan (Figure 5.2).
The typical urban typologies represent different spatial characteristics (Table 3.1) and the most common functions adapted to the former harbour sites are: (1) port-industrial, (2) new business, (3) residential and (4) residential waterfront (see chapter 3.1.1 under the subtitle of 'variables'). These common development orientations are extensively applied to harbour redevelopment projects and in post-industrial urban plans for transforming the former harbour areas into new living and working environments.

*[sRQ2 & 3] What are the contributions of different types of vegetation in urban streets to improve perceived thermal comfort and attractiveness of different functional zones in harbour contexts?*
Second, a visual questionnaire survey were developed (see chapter 3.1) and applied to investigate people's perception of (1) no vegetation, (2) ground and low-height vegetation, (3) wall vegetation and (4) trees associated with thermal comfort and attractiveness of the four harbour functional zones.

The contributions of each greenery type to people's perceived thermal comfort and attractiveness were illustrated in chapter 2.3, followed by chapter 2.4 which describes the impacts of the interaction between the existing urban built form and vegetation on people's perception in relation to their thermal comfort conditions and aesthetic appreciation. The questionnaire results (see chapter 3.2.3) confirmed the previous studies and also answered sRQ2 & 3 associated with perceived thermal comfort and attractiveness.

In general, street greenery improves thermal comfort conditions within urban canyons by providing shade, sheltering people from the unpleasant summer sun and cooling the air through evapotranspiration. These are the physical functions of the urban vegetation. Besides, psychological functions of urban vegetation involves visibility and spatial experience provided by the plants in different forms, colours, textures etc.
The role of different greenery types in improving perceived outdoor thermal comfort and attractiveness demonstrates the following:

**Ground and low-height vegetation** (e.g. grass, shrubs, bushes, hedges, and planting beds etc.) represents horizontal green feature that reflects an open structure of the space, also it supports the possibility of outdoor activities (e.g. resting, sun-bathing, reading, eating, sleeping etc.). Therefore, ground and low-height vegetation is suitable for residential waterfront, where people prefers to have open views and more spaces for leisure activities.

By contrast, in port-industrial area ground and low-height vegetation should be implemented not for recreational but transportation purposes by replacing the pavements with ground vegetation covers (e.g. grass pavers).

**Wall vegetation** in the form of green walls and green façades are considered as both thermally comfortable and attractive in new business area. Due to large building surfaces are covered by vegetation, which helps to decrease the surface temperature and cool the air. Furthermore, it looks greener from pedestrian's point of view and gives people refreshing feelings. Additionally, wall vegetation integrated into the existing urban structures such as building façades and walls are beneficial for shaping harbour characters and thus enhancing the attractiveness of port-industrial area.

**Trees** is the most observable green elements (3D objects) in street canyons and it possesses physical features such as heat absorption and thermal conductivities that helps to regulate thermal conditions. Also, the shading effects of trees significantly contributes to people's thermal perception and attractiveness of outdoor spaces especially in hot summer days. In residential area people valued trees both in physical as well as in psychological terms. Also, residents associated trees with biodiversity that creates natural habitat for birds and this increases the aesthetic appreciation of the neighbourhoods.

Based on the empirical evidence, it is recommended to use different types of street greenery, especially trees combined with other green elements, to design the streetscapes according to the harbour functional zone (see chapter 4). Besides, enhancing the visibility of street greenery is expected to have positive effects on improving people's perceived thermal comfort and aesthetic appreciation.

*[DQ1] How can design guidelines be implemented on urban streets with different functions and street configuration in the Rotterdam harbour areas?*

The general design guidelines and practical design recommendations for each functional zone were presented in chapter 4. These design guidelines were then implemented into the case study area of Merwe-Vierhavens in Rotterdam (see chapter 5).

The application of design guidelines can be processed by taking three steps:

*Background analysis*

First of all analysing the intensity of heat island effects in the selected site as the main problem to be solved. Next identifying the spatial context according to function and spatial characteristic through site analysis. It is important to analyse the existing built environment and street geometry such as aspect ratio, because it determines 'what and how' greenery types will be implemented into the street canyons. Then investigating original green structure helps to preserve the existing green areas and to make use of local green elements for designing the streetscapes by means of street greenery.

*Developing design guidelines*

According to the site analysis, the general design guidelines should be modified and adapted to site-specific context in order to fit into the selected site. For example, the spatial profile of the street such as street width and underground infrastructure are crucial factors that affects the implementation of street greenery. Different alternatives of greenery types can be applied in order to optimise the benefits in terms of thermal comfort and attractiveness.

*Design guidelines application*

Finally the design guidelines can be implemented and subsequently developed the detailed design. The further detailed design includes the street furniture in response to people's need for outdoor activities (e.g. benches, bicycle parking racks etc.) and safety consideration (e.g. street lighting facilities).

A few studies have indicated the contribution of street greenery in relation to people's perceived thermal comfort and aesthetic appreciation.

Lenzholzer & Koh (2010) reported that there are significant correlations between people's perception of the spatial environments and their thermal experience. In addition, Klemm et al. (2015ab) demonstrated the relations between green spaces and people's long-term perceived thermal comfort and aesthetic appreciation associated with the evaluation of green street design.

Based on these earlier studies and the research findings presented in this thesis, it is assumed that people's perceived thermal comfort and aesthetic appreciation are influenced by individual positive experience both spatially and visually related to street greenery (Figure 6.1).

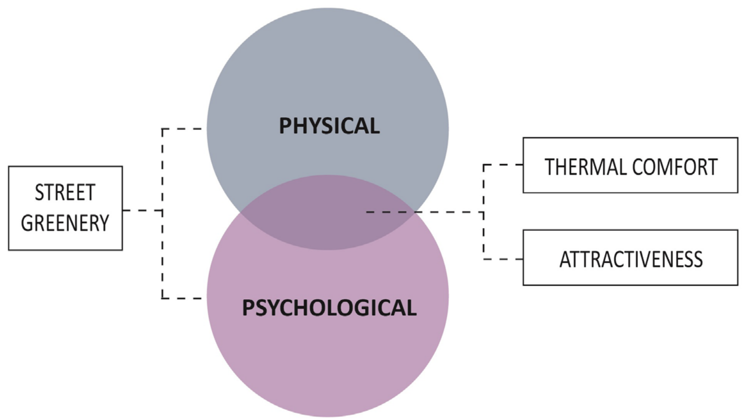



Figure 6.1 The contribution of street greenery in relation to thermal comfort and attractiveness

More in-depth studies on the impacts of street greenery on people's perceived thermal comfort and attractiveness from a psychological perspective are needed to investigate the link between street greenery and people's environmental experiences in terms of thermal perception and aesthetic appreciation.

*- Value of this research*

This thesis contributes to the redevelopment of harbour areas being converted into more liveable urban environments by proposing empirical-based design guidelines for thermally comfortable and attractiveness streetscapes in harbour contexts.

The general design guidelines can be applied globally to other port cities under similar weather conditions and circumstances. However, the follow-up design phases should be localised and focus on site-specific characteristics.

In the present study, visual questionnaire surveys were conducted in the city of Rotterdam to investigate the impacts of different types of street greenery on people's long-term perceived thermal comfort and aesthetic appreciation. In other words, the research methodology by means of questionnaire surveys designed in a visual approach can also be applied to any other cities for empirical data collection.

To conclude, the contributions of this thesis were summarised into two aspects: research methods and design practice.
On one hand, the value of using questionnaire survey for developing empirical-based design guidelines is that this research method (i.e. research through designing) involves design activity, which helps to investigate the design role of street greenery in shaping people's perceived outdoor thermal comfort and attractiveness.
On the other hand, the design guidelines supports landscape architects and urban planners to design suitable types of street greenery within various spatial harbour zones in harbour redevelopment projects and post-industrial urban plans. By applying the generated design guidelines in former harbour areas new living and working environments with thermally comfortable and attractive streetscapes can be created.
Furthermore, this thesis especially contributes to the ongoing harbour transformation plan of Merwe-Vierhavens in Rotterdam.

## 6.2 Recommendations for Further Research

This research attempts to provide evidence-based knowledge on perceived thermal comfort and attractiveness in connection with people's perception of different greenery types for design guidelines generation. However, the completion of this thesis is not a destination but a start of the investigation of this research subject and should be continued. More insights into the effects of urban vegetation on people's perceived thermal comfort and aesthetic appreciation from a psychological perspective are needed to broaden the sphere.

Some possible directions and recommendations for further research on perceived thermal comfort and attractiveness based on people's perception of street greenery are provided as follow:

*- Diversify the alternatives by combining different types of street greenery*

In the present research, four design alternatives of street greenery (no vegetation, ground and low-height vegetation, wall vegetation, trees) were developed in order to investigate people's perceived thermal comfort and aesthetic appreciation related to street greenery. Different types of street greenery were evaluated by people respectively by means of visual questionnaire and subsequently analysed to formulate design guidelines.

However, this study focuses on the evaluation of each single green element and generates design guidelines by combining different greenery types based on the empirical survey results. It is recommended to diversify the design alternatives of street greenery by combining different green elements in the visual questionnaire for further research. In this way, the relative influence of greenery types on perceived thermal comfort and attractiveness can be assessed. This provides detailed evidence-based data and supports the development of design guidelines more precisely.

*- Apply physical (micrometeorological measurements) and psychological (field study) for comparison*

For investigating the impact of street greenery on people's perceived thermal comfort, it is recommended to apply both physical and psychological approaches to conduct the research. For example, Klemm et al. (2015ab) demonstrated a strong correlation between street greenery and people's long-term thermal experience by means of micrometeorological measurements and semi-structured interviews. The empirical data obtained from the field study can be compared with the physical measurements in order to evaluate the relative significance of psychological parameters.

*- Take cultural and geographical background into account*

It is noticeable that people's perceptions are largely derived from individual backgrounds and personal value judgments. Take the case study area of this research as an example, Rotterdam is well-known as a cultural melting pot with mixed nationalities. In consequence, people from other countries with different geographic circumstances may influence their microclimate attitudes and environmental preferences during the questionnaire survey. However, the influences of respondents' cultural backgrounds and ethnic characteristics on their perception in terms of thermal comfort and aesthetic appreciation are not being discussed in this study. But this could be an interesting topic for further research.

## 6.3 Reflection

*- The development of design guidelines*

The design guidelines for thermally comfortable and attractive streetscapes were developed based on the results of empirical study.

On one hand, it is important to collect ample empirical data that supports the development of evidence-based design guidelines. In the present study, different strategies (online and face-to-face surveys) were applied in order to maximise the amount of data.

On the other hand, the design of the questionnaire surveys directly affects response rate and therefore has a considerable role in developing design guidelines.

Concerning the influences of survey length on response rate, some design alternatives of street greenery has to be taken out and compressed the questionnaire for the purpose of reducing dropouts and keeping respondents' attention focused. To some extent this limits the research contents and thus could be influencing the development of design guidelines.

Other potential difficulties and limitations of the study design were described in chapter 3.3, and the possible directions and recommendations for further research were mentioned above in chapter 6.2.

# Reference

**K** Klemm, W., Heusinkveld, B. G., Lenzholzer, S., & van Hove, B. (2015b). Street greenery and its physical and psychological impact on thermal comfort. Landscape and Urban Planning.

Klemm, W., Heusinkveld, B. G., Lenzholzer, S., Jacobs, M. H., & Van, H. B. (2015a). Psy-chological and physical impact of urban green spaces on outdoor thermal comfort during summertime in The Netherlands. Building and Environment, 83, 120-128.

**L** Lenzholzer, S., & Koh, J. (2010). Immersed in microclimatic space: Microclimate experi-ence and perception of spatial configurations in Dutch squares. Landscape and Urban Planning, 95, 1-15.

Photo credit: Green façade: MMA Architectural Systems. Retrieved from http://www.buildingpieces.com/products-info/groupIds/22/productId/680/subCatId/59/catId/0

Appendix I: Research through designing: the process of developing the visualisation images for the questionnaire

Appendix II: Questionnaire

Appendix III: Keywords provided by survey respondents for their preferences in relation to thermal comfort and attractiveness

List of Figure

List of Table

The process of developing the visualisation images for the questionnaire can be basically divided into three stages, as shown on the following pages.

The first stage focuses on the selection of background images and the setting of alternatives related to street greenery. Different photographs were tested for finding out the most suitable background images to represent each functional zone in harbour contexts.

1st version of the visualisation contained 8 greenery alternatives according to the amount of vegetation in three spatial contexts (port-industrial; new business; residential)

The second stage concerns the design of street greenery in terms of the amount of vegetation, different green elements used to represent each vegetation type and tree sizes etc.

2nd version of the visualisation included 5 greenery alternatives (no vegetation, ground and low-height vegetation, wall vegetation, trees, green areas) in three spatial contexts (port-industrial; new business; residential)

The last stage attempts to develop different street widths (narrow versus broad) for comparison. However, the results show that the difference between narrow and broad streets were indistinct and thus were discarded from the design of visual stimuli.

3rd version of the visualisation covered 4 greenery alternatives (no vegetation, ground and low-height vegetation, wall vegetation, trees) in four spatial contexts (port-industrial; new business; residential; residential waterfront) with different street widths (narrow and broad)

This stage three different types of street greenery (ground and low-height vegetation, wall vegetation, trees) were specified. Subsequently, the position of trees (e.g. in the middle or on one/ both side(s) of the street) were tested.

Date:
Time:
Weather condition:

**Intro** This research survey is conducted for my graduation project (Wageningen UR Landscape Architecture) and as part of research study of the transformation project of Merwe-Vierhavens for the municipality of Rotterdam. (Gemeente Rotterdam)

The aim of this research is to investigate local people's perception of outdoor spaces. With this survey analyses thermal comfort and attractiveness of outdoor spaces in a harbor area. Thermal comfort refers to the perception of all kinds of weather aspects like sun, wind, shadow, and humidity...etc.

Are you living or working in Rotterdam?
Would you like to share your ideas and experiences by taking part in this survey?

Answering the questionnaire may take about 10 minutes of your time. The information you provide will remain anonymous and only be used for research purpose. Thank you for taking the time to complete this survey and I greatly appreciate your contribution to my research.

WAGENINGEN UR For quality of life

Gemeente Rotterdam

Christy Tang
christy.tang@wur.nl
c.tang@rotterdam.nl

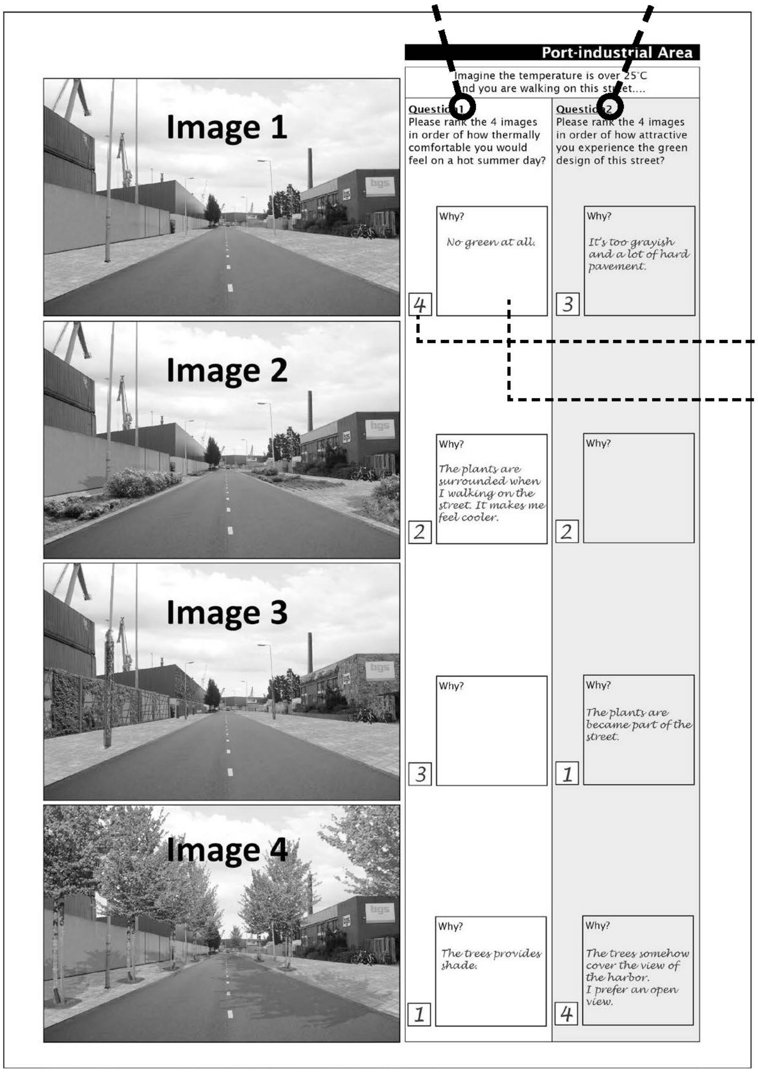
On the following pages you will see a series of images in 4 functional zones.
Each of the functional zones will be represented by 4 images.

You are asked to rank the 4 images on each page using a scale from 1 to 4, **according to**

**1)** ***How thermally comfortable you would feel on a hot summer day.***

**2)** ***How attractive you experience the green design of this street.***

Example:




Ranking
in order from 1 (best) to 4 (least)

Briefly describe the reasons

**Background information**

Gender: ☐ Male ☐ Female
Age: __________

Where do you live in Rotterdam (Please fill in a street name): ________________________

# Port-industrial Area

Imagine the temperature is over 25°C
and you are walking on this street....





| **Question1**<br>Please rank the 4 images in order of how thermally comfortable you would feel on a hot summer day? | **Question2**<br>Please rank the 4 images in order of how attractive you experience the green design of this street? |
|---|---|
| Why? | Why? |
| Why? | Why? |
| Why? | Why? |
| Why? | Why? |

## New Business Area

Imagine the temperature is over 25˚C
and you are walking on this street....

| **Question1**<br>Please rank the 4 images in order of how thermally comfortable you would feel on a hot summer day? | **Question2**<br>Please rank the 4 images in order of how attractive you experience the green design of this street? |
|---|---|

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | Why? | | Why? |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | Why? | | Why? |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | Why? | | Why? |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | Why? | | Why? |

## Residential Area

Imagine the temperature is over 25˚C
and you are walking on this street....

| Image | Question1<br>Please rank the 4 images in order of how thermally comfortable you would feel on a hot summer day? | Question2<br>Please rank the 4 images in order of how attractive you experience the green design of this street? |
|---|---|---|
|  | ☐ Why? | ☐ Why? |
|  | ☐ Why? | ☐ Why? |
|  | ☐ Why? | ☐ Why? |
|  | ☐ Why? | ☐ Why? |

## Waterfront

Imagine the temperature is over 25˚C
and you are walking on this street....

| **Question1** Please rank the 4 images in order of how thermally comfortable you would feel on a hot summer day? | **Question2** Please rank the 4 images in order of how attractive you experience the green design of this street? |
|---|---|

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | | | |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | | | |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | | | |

| Rank | Why? | Rank | Why? |
|---|---|---|---|
| | | | |

## *Port-Industrial Area*

**Thermal Comfort**: Green Infrastructure; Perception; Microclimate Parameters

**Attractiveness**: Aesthetic Reasons; Design Qualities; Environmental Benefits

| Ranking | Thermal comfort N | % | Attractiveness N | % |
|---|---|---|---|---|
| 1st | 1 | 0.9 | 1 | 0.9 |
| 2nd | 2 | 1.9 | 11 | 10.4 |
| 3rd | 7 | 6.6 | 15 | 14.1 |
| 4th | 96 | 90.6 | 79 | 74.6 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>\\<br>(−)<br>No nature; no trees; no green; less green; not enough green; no shelter; no protection; bald; arid | Keywords<br>(+)<br>\\<br>(−)<br>Open; too wide; bare; empty; the street looks longer and without a place for resting on hot summer days | Keywords<br>(+)<br>\\<br>(−)<br>Concrete retains heat and radiates warmth; stony; hard; only buildings; greyish; high density of heat storage materials; heat radiating surfaces | Keywords<br>(+)<br>\\<br>(−)<br>Too quiet; impersonal; cold; ugly; boring; blank; bad; uninviting; bare; too industrial; dead; lifeless; unenjoyable ; repulsive | Keywords<br>(+)<br>Open view; see more surroundings<br>(−)<br>No street greenery; not enough greenery; bald; empty; too bare for enjoying the weather | Keywords<br>(+)<br>\\<br>(−)<br>No room for animal and plant habitats |

| Ranking | Thermal comfort N | % | Attractiveness N | % |
|---|---|---|---|---|
| 1st | 1 | 0.9 | 8 | 7.5 |
| 2nd | 55 | 51.9 | 40 | 37.7 |
| 3rd | 48 | 45.3 | 45 | 42.5 |
| 4th | 2 | 1.9 | 13 | 12.3 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Natural; green; greener; vegetation; planting; bushes; shrubs; flowers; lawns; horizontal green; green presence; shrubbery reduces heat<br>(−)<br>Some green | Keywords<br>(+)<br>Green view; open; more open ground; street-like; green at eye level<br>(−)<br>\\ | Keywords<br>(+)<br>More green cover; grass paver; soft surfaces; less stone surfaces; less paving; wind; fresh<br>(−)<br>No shadow | Keywords<br>(+)<br>Garden-like; lots of different plants; simple; nice atmosphere; flowers make the street happier; beautiful; pleasant<br>(−)<br>Almost no difference; boring; noting special | Keywords<br>(+)<br>Open view; green view; not too wide; green elements are integrated into the street configuration; wild (character)<br>(−)<br>Too less green; messy | Keywords<br>(+)<br>Species diversity; low vegetation (green on the soil surface) improve water storage; shrubs and planting beds are good for animals and water storage<br>(−)<br>\\ |

| Ranking | Thermal comfort N | % | Attractiveness N | % |
|---|---|---|---|---|
| 1st | 2 | 1.9 | 10 | 9.4 |
| 2nd | 47 | 44.3 | 44 | 41.5 |
| 3rd | 51 | 48.1 | 41 | 38.7 |
| 4th | 6 | 5.7 | 11 | 10.4 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Green; greener; climbing plants on the wall; green on buildings; vertical green; leaves absorb heat<br>(−)<br>A little bit of green; gross; messy; only green on walls and lamp poles | Keywords<br>(+)<br>Green view; spacious; green at eye level; looks cooler; feels better; vertial greening provide greater visual variety<br>(−)<br>\\ | Keywords<br>(+)<br>Green surfaces; colors on the wall; colored buildings; open space for wind to blow; air flow; fresh; brown fence 'cooler' than the gray<br>(−)<br>Wet; humid; stifling | Keywords<br>(+)<br>Cozy; colorful; friendly; beautiful; artistic; full of art spirit; good; special; nice and still; interesting; fairly well<br>(−)<br>Untidy; green attached to the buildings is unnatural | Keywords<br>(+)<br>Open view; spacious; green on buildings but still can see some concrete; greenery is part of the landscape<br>(−)<br>Only vertical greening; overdesign for a working area | Keywords<br>(+)<br>Green spaces for birds; habitat for animals; good combination of green and urban<br>(−)<br>\\ |

| Ranking | Thermal comfort N | % | Attractiveness N | % |
|---|---|---|---|---|
| 1st | 102 | 96.2 | 87 | 82.1 |
| 2nd | 2 | 1.9 | 11 | 10.4 |
| 3rd | 0 | 0 | 5 | 4.7 |
| 4th | 2 | 1.9 | 3 | 2.8 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Natural; green; most green; lots of trees; trees provide shade; sheltered from solar radiation; evaporation loss of trees; presence of trees<br>(−)<br>Trees cover too much | Keywords<br>(+)<br>Bright; green view; looks nice; the greener the better/ more comfortable; the trees create a rhythm (enrichment) that makes the street looks shorter<br>(−)<br>Too crowded | Keywords<br>(+)<br>Fresh, breath; breezy; trees sheltered people from direct sunlight, wind, and rain; shadows; more shadows; trees provide shelter from windy (harbor) weather<br>(−)<br>\\ | Keywords<br>(+)<br>Very attractive; friendly; inviting; most beautiful; cozy; safe; nice; nicer; clean; trees add beauty to the port, create varying effects/ richer experience<br>(−)<br>Scary; boring; traditional | Keywords<br>(+)<br>Vivid; less abandoned; trees provide a green frech look and mask the ugly industrial site<br>(−)<br>No variation; narrow; too much green decorations for a working area | Keywords<br>(+)<br>City need trees to breathe; better air quality; provide nice break between industrial area; lively; habitat for animals; fauna<br>(−)<br>\\ |

## *New Business Area*

| | Thermal Comfort | | | Attractiveness | | |
|---|---|---|---|---|---|---|
| | **Green Infrastructure** | **Perception** | **Microclimate Parameters** | **Aesthetic Reasons** | **Design Qualities** | **Environmental Benefits** |
|  | Keywords<br>(+)<br>\<br>(−)<br>No green; no trees; bald; no shelter; arid | Keywords<br>(+)<br>\<br>(−)<br>Empty; looks hot | Keywords<br>(+)<br>\<br>(−)<br>Too much concrete; stony; high rise buildings and surface glasses has the warming effect; greyish; no shadow; no shelter; high density of heat storage materials | Keywords<br>(+)<br>\<br>(−)<br>Boring; simple; cold (color); uninviting; no colors; too dry and industrial | Keywords<br>(+)<br>Open view<br>(−)<br>No street greenery; too empty; too bare for enjoying the weather | Keywords<br>(+)<br>\<br>(−)<br>\ |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 1 | 0.9 | 3 | 2.8 |
| 2nd | 0 | 0 | 7 | 6.6 |
| 3rd | 7 | 6.6 | 15 | 14.1 |
| 4th | 98 | 92.5 | 81 | 76.5 |
| Total | 106 | 100 | 106 | 100 |

| | Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|---|
|  | Keywords<br>(+)<br>Green; greener; orderly; low vegetation; lawns; horizontal green; presence of green; green is closer to people<br>(−)<br>Some green; only grass; only low plants | Keywords<br>(+)<br>Better overview; open; spacious; more open ground; green at eye level; fresh view; the greener the better/ more comfortable/ healthier; segmentation of spaces<br>(−)<br>\ | Keywords<br>(+)<br>Soft; replacing the heat-radiating surfaces by green; less stone surfaces and less reflection of sun<br>(−)<br>No shadow; no protection from direct sunlight and wind | Keywords<br>(+)<br>Simple; nice; more colors; colorful; friendly; cozy; sociable; beautiful<br>(−)<br>Good but too simple; nothing special; boring; no difference; traditional; basic | Keywords<br>(+)<br>Green makes the harbor area more suitable for peopleto walk and other human activities; greenery in varied heights for visual enjoyment<br>(−)<br>\ | Keywords<br>(+)<br>Green on the soil surface give suggestive of more water storage and evaporation loss; shrubs and planting beds are good for animals and water storage; possibility for building rain gardens<br>(−)<br>\ |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 1 | 0.9 | 1 | 0.9 |
| 2nd | 38 | 35.9 | 41 | 38.7 |
| 3rd | 64 | 60.4 | 53 | 50 |
| 4th | 3 | 2.8 | 11 | 10.4 |
| Total | 106 | 100 | 106 | 100 |

| | Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|---|
|  | Keywords<br>(+)<br>Green; green façade; green screen/ fence/ wall; vertical green; presence of green; greening high rise buildings; lots of green on buildings; presence of green<br>(−)<br>\ | Keywords<br>(+)<br>Looks like the coolness will arrive at the volume but not just on the ground level; green on street level<br>(−)<br>\ | Keywords<br>(+)<br>Transparent; fresh; clean; buildings are colored<br>(−)<br>Humid; a little bit of shadows; stifling | Keywords<br>(+)<br>Modern; new; sociable; professional; friendly; inviting; relaxing; cozy; beautiful; attractive; nice; creative; artistic; vivid; innovative; cool; something going on<br>(−)<br>Unnatural; artificial; ugly | Keywords<br>(+)<br>Open view; high quality of public space; fits the surroundings; overview; good combination of green and urban; vertical vegetation suggests privacy<br>(−)<br>\ | Keywords<br>(+)<br>Biodiversity<br>(−)<br>Green but not helping with ecology |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 10 | 9.4 | 26 | 24.5 |
| 2nd | 61 | 57.6 | 39 | 36.8 |
| 3rd | 32 | 30.2 | 31 | 29.3 |
| 4th | 3 | 2.8 | 10 | 9.4 |
| Total | 106 | 100 | 106 | 100 |

| | Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|---|
|  | Keywords<br>(+)<br>Natural; trees; lots of trees; green; greener; trees provide shade; trees protect against the heat; shelter; green pathway; presence of trees<br>(−)<br>Shady | Keywords<br>(+)<br>The greener the better/ more comfortable; more accessible; street-like; the greener the better; most enjoyable for pedestrians; volume of green<br>(−)<br>Blocked the view | Keywords<br>(+)<br>Breezy; fresh; shadows; more shadows; a lot of shadows; trees provide cooling by sheltered pedestrians from solar radiation<br>(−)<br>\ | Keywords<br>(+)<br>Peaceful; beautiful; nice; attractive; good-looking; inviting; welcoming; cozy<br>(−)<br>Boring; nice but classic; traditional; normal; not spectacular | Keywords<br>(+)<br>Nice to walk under the trees; business area need shaded space for parking<br>(−)<br>Too much trees/ leaves (mask the surroundings and hard to maintain); too crowded | Keywords<br>(+)<br>Better air quality; habitat for animals and ecosystem services<br>(−)<br>\ |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 94 | 88.7 | 76 | 71.7 |
| 2nd | 7 | 6.6 | 19 | 17.9 |
| 3rd | 3 | 2.8 | 7 | 6.6 |
| 4th | 2 | 1.9 | 4 | 3.8 |
| Total | 106 | 100 | 106 | 100 |

## *Residential Area*

| | Thermal Comfort | | | Attractiveness | | |
|---|---|---|---|---|---|---|
| | **Green Infrastructure** | **Perception** | **Microclimate Parameters** | **Aesthetic Reasons** | **Design Qualities** | **Environmental Benefits** |
|  | Keywords<br>(+)<br>\\<br>(−)<br>No green; no trees; bald; bare; no shelter | Keywords<br>(+)<br>Open<br>(−)<br>Bare | Keywords<br>(+)<br>\\<br>(−)<br>Too much concrete; stony; no shadow; no protection | Keywords<br>(+)<br>\\<br>(−)<br>Boring; colorless; dead; lifeless | Keywords<br>(+)<br>Open view<br>(−)<br>No street greenery; too bare for enjoying the weather | Keywords<br>(+)<br>\\<br>(−)<br>No room for animal and plant habitats |
|  | Keywords<br>(+)<br>Greener; grass; grass paver; green parking; lawns; horizontal green; presence of green<br>(−)<br>Some green; looks like weeds | Keywords<br>(+)<br>Restful; smoothing; green at eye level; Visual segmentation of spaces; the greener the better/ more comfortable<br>(−)<br>Cars hide the low vegetation and make it less visible | Keywords<br>(+)<br>Green parking lots looks less warm, grass paver is cooler than walk on the concrete/ asphalt; less pavement; replacing the heat-radiating surfaces by green; softening<br>(−)<br>No shadow | Keywords<br>(+)<br>Inviting; cozy; restful; beautiful; more beautiful; attractive; pretty; soft; pleasant<br>(−)<br>The grass paver is ugly and looks dirty | Keywords<br>(+)<br>Clear green structure; fits the surroundings<br>(−)<br>Only greening the parking lots; too flat; no trees; greening parking is good but it drag people's attention on it; difficult to walk on green parking | Keywords<br>(+)<br>Habitat for animals; lawns and shrubs carry water (water storage)<br>(−)<br>\\ |
|  | Keywords<br>(+)<br>Green; flowers; planting; flowering balcony; climbing plants on the lamp poles; greenery can distract my attention from the heat<br>(−)<br>Messy | Keywords<br>(+)<br>Open but not too wide; volume of green<br>(−)<br>Bare; green walls are too much in the edge of the street and thus out of sight; less visible | Keywords<br>(+)<br>Air circulation; better air quality; heat insulation<br>(−)<br>Stifling; some green but still quite stony | Keywords<br>(+)<br>Colorful; happy; cozy; beautiful; prettier; nice; interesting; uncommon; delightful; vivid; more attractive; refreshing; variety; innovative<br>(−)<br>Disturbing; messy | Keywords<br>(+)<br>Parking lots are less visible; smell (sensing experience); interesting greening approach; lighting (safety); green elements integrated with the architecture<br>(−)<br>Too much for a living area; not feasible | Keywords<br>(+)<br>Flowering balconies offer local residents to involve greening action (public involvement); species diversity<br>(−)<br>\\ |
|  | Keywords<br>(+)<br>Green; trees; huge trees; natural; shelter; protective; trees provide shade; trees protect people from the direct sunlight but not too bushy; sheltered from solar radiation<br>(−)<br>Too shady | Keywords<br>(+)<br>Trees along the street helps pedestrian to walk in the shadows on hot summer days (leading); trees are more visible; the greener the better/ more comfortable<br>(−)<br>Too dark | Keywords<br>(+)<br>Wind blows; breezy; a lot of shadows; humidity; tree leaves slow down falling raindrops (rain protection)<br>(−)<br>\\ | Keywords<br>(+)<br>Pleasant; cozy; relaxing; cheerful; delightful; nice; trees add beauty to the neighborhood; homey; visually appealing<br>(−)<br>Normal; ordinary; common; traditional | Keywords<br>(+)<br>Huge trees; greenery gives pleasant feeling to the people; decorated by trees; sound of wind and leaves; bird singing (sensing experience)<br>(−)<br>No lighting; traditional; maintenance of trees | Keywords<br>(+)<br>Tree collect raindrops; green spaces for birds; habitat for animals; biodiversity; trees also protect residents from the cold in winter.<br>(−)<br>The shade of trees may block natural light in the house |

Ranking tables below the images:

| | Thermal comfort | | Attractiveness | |
|---|---|---|---|---|
| Ranking | N | % | N | % |
| 1st | 1 | 0.9 | 2 | 1.9 |
| 2nd | 1 | 0.9 | 4 | 3.8 |
| 3rd | 4 | 3.8 | 15 | 14.1 |
| 4th | 100 | 94.4 | 85 | 80.2 |
| Total | 106 | 100 | 106 | 100 |

| | Thermal comfort | | Attractiveness | |
|---|---|---|---|---|
| Ranking | N | % | N | % |
| 1st | 0 | 0 | 2 | 1.9 |
| 2nd | 40 | 37.8 | 47 | 44.3 |
| 3rd | 63 | 59.4 | 45 | 42.5 |
| 4th | 3 | 2.8 | 12 | 11.3 |
| Total | 106 | 100 | 106 | 100 |

| | Thermal comfort | | Attractiveness | |
|---|---|---|---|---|
| Ranking | N | % | N | % |
| 1st | 8 | 7.5 | 10 | 9.4 |
| 2nd | 59 | 55.7 | 48 | 45.3 |
| 3rd | 38 | 35.9 | 42 | 39.6 |
| 4th | 1 | 0.9 | 6 | 5.7 |
| Total | 106 | 100 | 106 | 100 |

| | Thermal comfort | | Attractiveness | |
|---|---|---|---|---|
| Ranking | N | % | N | % |
| 1st | 97 | 91.5 | 92 | 86.8 |
| 2nd | 6 | 5.7 | 7 | 6.6 |
| 3rd | 1 | 0.9 | 4 | 3.8 |
| 4th | 2 | 1.9 | 3 | 2.8 |
| Total | 106 | 100 | 106 | 100 |

## *Residential Waterfront*

Thermal Comfort: Green Infrastructure; Perception; Microclimate Parameters
Attractiveness: Aesthetic Reasons; Design Qualities; Environmental Benefits

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 2 | 1.9 | 3 | 2.8 |
| 2nd | 5 | 4.7 | 12 | 11.3 |
| 3rd | 7 | 6.6 | 14 | 13.2 |
| 4th | 92 | 86.8 | 77 | 72.7 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>\<br>(–)<br>No green; bald | Keywords<br>(+)<br>Open view<br>(–)<br>Too open; empty; bare; looks cold without greenery | Keywords<br>(+)<br>The cooling effect of wind and water<br>(–)<br>Too windy; concrete retains heat and radiates warmth; hard and stony; greyish | Keywords<br>(+)<br><br>(–)<br>Boring; simple; cold; chilly; dead; lifeless | Keywords<br>(+)<br>Open view<br>(–)<br>No street greenery; empty | Keywords<br>(+)<br>\<br>(–)<br>No room for animal and plant habitats |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 4 | 3.8 | 9 | 8.5 |
| 2nd | 55 | 51.8 | 48 | 45.3 |
| 3rd | 40 | 37.8 | 33 | 31.1 |
| 4th | 7 | 6.6 | 16 | 15.1 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Green; greener; grass; planting; horizontal green; green riverbank<br>(–)<br>Some green; looks like weeds; looks like the cooling effect is low | Keywords<br>(+)<br>Open; view of water; green at eye level; visual segmentation of spaces<br>(–)<br>\ | Keywords<br>(+)<br>Fresh; soft surfaces; less stone surfaces; less pavement; replacing the heat-radiating surfaces by green; wind blows; breezy<br>(–)<br>\ | Keywords<br>(+)<br>Fresh; very good; basic but it works; pleasant; beauriful; inviting; spacious<br>(–)<br>Usual; normal | Keywords<br>(+)<br>Open view; nice combination of natural elements: water-land-vegetation; wild grass shape its character; open structure is suitable for the waterfront; soft edges<br>(–)<br>Too less green; no trees | Keywords<br>(+)<br>Lawns and shrubs carry water (water storage)<br>(–)<br>\ |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 9 | 8.5 | 9 | 8.5 |
| 2nd | 40 | 37.8 | 35 | 33.1 |
| 3rd | 54 | 50.9 | 54 | 50.9 |
| 4th | 3 | 2.8 | 8 | 7.5 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Green; greenery; green on buildings; flowers; flowering balcony; orderly; vertical green<br>(–)<br>Not much green; gross | Keywords<br>(+)<br>Overview<br>(–)<br>Too much; green in the edge of the street and thus out of sight; less visible | Keywords<br>(+)<br>Wind; air flow; can see the wind blowing through the wind turbine on top of street lighting; a little bit of shadows<br>(–)<br>Humid; lots of concrete/ asphalt; greyish | Keywords<br>(+)<br>Modern; homey; good; pleasant; interesting<br>(–)<br>contrived; unnatural; too much; complicated; unfriendly; distracting | Keywords<br>(+)<br>Nice view; overview; street lighting give the feeling of safety; greenery combined with street lighting design<br>(–)<br>The design of lighting; the lamp poles in the middle of the street | Keywords<br>(+)<br>The combination of greenery and flowers are healthy<br>(–)<br>\ |

| Ranking | Thermal comfort N | Thermal comfort % | Attractiveness N | Attractiveness % |
|---|---|---|---|---|
| 1st | 91 | 85.8 | 85 | 80.2 |
| 2nd | 6 | 5.7 | 11 | 10.4 |
| 3rd | 5 | 4.7 | 5 | 4.7 |
| 4th | 4 | 3.8 | 5 | 4.7 |
| Total | 106 | 100 | 106 | 100 |

| Green Infrastructure | Perception | Microclimate Parameters | Aesthetic Reasons | Design Qualities | Environmental Benefits |
|---|---|---|---|---|---|
| Keywords<br>(+)<br>Trees; shade trees; green; flowering balcony; trees provide shade; shelter; orderly; presence of water (cooling); tree lane<br>(–)<br>Too much trees; trees are too big; overprotective | Keywords<br>(+)<br>Tree is eye-catching; restful; the greener the better<br>(–)<br>Trees deprive residents' view; water less visible | Keywords<br>(+)<br>Wind; breezy; shadows; trees prevent colar radiation<br>(–)<br>\ | Keywords<br>(+)<br>Beautiful; attractive; relaxing; nice; park-like; typical Dutch<br>(–)<br>Traditional; boring, too much | Keywords<br>(+)<br>Nice combination of natural elements: water-land-vegetation; sound of wind and leaves (sensing experience)<br>(–)<br>Less view; leaves mask the view of water from houses; too dominant | Keywords<br>(+)<br>The added values of trees<br>(–)<br>\ |

# List of Figure


**Figure 1.1** Redevelopment of former port area for new city district; HafenCity Hamburg, Germany *2*
**Figure 1.2** From industrial area to sustainable city;Western Harbour Malmö, Sweden *2*
**Figure 1.3** Using street trees and vegetation in the design of urban streets and pedestrian areas; Downtown Seattle, Washington, USA *3*
**Figure 1.4** Urban heat island during the day and night *4*
**Figure 1.5** Heat sources and reflections inside urban canyons that cause urban heat island *5*
**Figure 1.6** Surface heat island (SHI) effect in Dutch cities during the day and night *6*
**Figure 1.7** Urban heat island effect in 2050 based on the climate scenario *6*
**Figure 1.8** Research framework *10*
**Figure 1.9** Research process flowchart *11*
**Figure 1.10** The concept-test model: testing a series of concepts on the design problem, modifying one or more of them for finding the most suitable options and identifying a general preference as solution for the problem *13*
**Figure 1.11** The systematic model: the research (triangular forms) determines the concept (oval), and the concept is a tool for transmitting the integrated complexities of the site (rectangle) *14*
**Figure 1.12** Study area (including Schiedam and Capelle aan den Ijssel); the yellow box indicates the location of Merwe-Vierhavens area *14*
**Figure 1.13** Average surface temperature in Rotterdam *15*
**Figure 1.14** Air temperature in the urban canopy layer in Rotterdam *15*
**Figure 1.15** Physiological equivalent temperature (PET) calculated from the results of Figure 1.14 *15*
**Figure 2.1** The new architecture for business, commercial, residential and cultural etc. non-port related functions *23*
**Figure 2.2** The preservation of historic buildings and harbour elements adapted for the new urban functions *24*
**Figure 2.3** The different scales of urban heat islands; UBL is the urban boundary layer, and UCL is the urban canopy layer *25*
**Figure 2.4** Thermal exchange between the human body and its environment. *27*
**Figure 2.5** The interrelationships between the different parameters of psychological adaptation in a network *28*
**Figure 2.6** Radiations and energy fluxes over an urban and a rural area on a clear day which contributes to the formation of urban heat islands *30*
**Figure 2.7** The formation of urban heat islands *31*
**Figure 2.8** Physical functions of urban vegetation (a) production of shade; (b) glare re-duction; (c) interception of dust *32*
**Figure 2.9** Scheme of the daytime energy exchanges between isolated tree and its street canyon environment *33*
**Figure 2.10** Psychological functions of urban vegetation (a) screening parking lots; (b) screening traffic; (c) aesthetic and sensory environment *34*
**Figure 2.11** Visualization of the four urban vegetation types according to Bowler et al. (2010) *34*
**Figure 2.12** Physical functions and thermal benefits of ground and low-height vegetation *35*
**Figure 2.13** Physical functions and thermal benefits of wall and roof vegetation *36*
**Figure 2.14** Physical functions and thermal benefits of trees *37*

**Figure 3.1** Schematic diagram of questionnaire design *46*
**Figure 3.2** Vegetation variables: four alternatives of different greenery types *47*
**Figure 3.3** Selected streets for taking pictures and the photo layout *48*
**Figure 3.4** Series of visualisation images featured with different greenery types (no vegetation, ground and low-height vegetation, wall vegetation, trees) within four harbour functional zones (port-industrial; new business; residential; residential waterfront) *50*
**Figure 3.5** Questionnaire covering letter *51*
**Figure 3.6** Example of how to fill in the questionnaire *51*
**Figure 3.7** Online survey distribution *52*
**Figure 3.8** Three urban locations in the city of Rotterdam for conducting face-to-face survey *52*
**Figure 3.9** Locations of homes or workplaces of the survey respondents in Rotterdam. The pins in different colours refers to the survey respondents approached by using different methods: (blue) online survey and (red) face-to-face survey *55*
**Figure 3.10** Age and gender composition of the survey respondents *55*
**Figure 3.11** Rankings of different greenery types from the best to the least in terms of thermal comfort and attractiveness within four harbour functional zones *56*
**Figure 3.12** Visualisation of the ranking results. Mean points of the four greenery types in each of the harbour functional zones distinguished by colours: (purple) port-industrial; (yellow) new business; (green) residential; (blue) residential waterfront *57*
**Figure 3.13** A comparison between the different greenery types in terms of thermal comfort and attractiveness in a port-industrial area. *59*
**Figure 3.14** A comparison between the different greenery types in terms of thermal comfort and attractiveness in a new business area. *60*
**Figure 3.15** A comparison between the different greenery types in terms of thermal comfort and attractiveness in a residential area. *61*
**Figure 3.16** A comparison between the different greenery types in terms of thermal comfort and attractiveness in a residential waterfront. *61*

**Figure 4.1** Sum points of the different greenery types in each of the four harbour functional zones. *69*
**Figure 4.2** Visualisation of the general design guidelines *69*

**Figure 5.1** Location of the main harbour sites within Stadshavens area in Rotterdam *75*
**Figure 5.2** Development scenario and zoning plan for Merwe-Vierhavens. According to Gemeente Rotterdam, 2011 *75*
**Figure 5.3** Average surface temperature of Rotterdam based on 15 Landsat images *76*
**Figure 5.4** Street analysis according to harbour functional zones in M4H area *77*
**Figure 5.5** Existing green structure and the typology of green areas in M4H area *78*
**Figure 5.6** Implementation of design guidelines: Port-industrial area *81*
**Figure 5.7** Implementation of design guidelines: New Business area *83*
**Figure 5.8** Implementation of design guidelines: Residential area *85*
**Figure 5.9** Implementation of design guidelines: Residential waterfront *87*

**Figure 6.1** The contribution of street greenery in relation to thermal comfort and attractiveness *98*

# List of Table


| | | |
|---|---|---|
| **Table 2.1** | The evolution of the port-city interface | *22* |
| **Table 2.2** | The distinction of characteristics between surface and atmospheric urban heat islands | *26* |
| **Table 2.3** | Ranges of physiological equivalent temperature (PET) indexes with different degrees of thermal perception by human beings | *28* |
| **Table 2.4** | Activities and affiliated PET values with the thermal sensation, these values were calculated based on measurements of different investigations in Germany | *29* |
| **Table 3.1** | Spatial variables: four harbour functional zones with different spatial characteristic | *47* |
| **Table 3.2** | Response outcomes (valid responses N=106) | *54* |
| **Table 3.3** | Mean points of the different greenery types in each of the four harbour functional zones; by using a scale range from 1 (least thermally comfortable to; least attractive) to 4 (most thermally comfortable; most attractive) (N=106, standard deviation in brackets) | *56* |
| **Table 3.4** | Six thematic categories with relation to thermal comfort and attractiveness for coding | *58* |
| **Table 3.5** | The example of keywords given by the respondents under the theme 'green infrastructure' with respect to thermal comfort | *58* |
| **Table 3.6** | The number of times being mentioned (N) and the frequency (%) of the keywords associated with thermal comfort | *63* |
| **Table 3.7** | The number of times being mentioned (N) and the frequency (%) of the keywords associated with attractiveness (green factors) | *63* |
| **Table 3.8** | The number of times being mentioned (N) and the frequency (%) of the keywords associated with attractiveness (other factors) | *63* |
| **Table 4.1** | Design guidelines and recommendations for the four functional zones in harbour contexts | *70* |
| **Table 5.1** | Port-city evolution timeline in Rotterdam. Inspired by Hoyle, 1989. | *74* |