Restorative value of the urban greenscape

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URBAN RESIDENTIAL STREETS AS RESTORATIVE ENVIRONMENTS

Robert van Dongen

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PROEFSCHRIFT

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door

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Preface

In 2012, my then director Leo Kemps dropped a flyer on my desk and said: *'Weren't you interested in doing a PhD some day?'* The flyer about the 'NWO Promotiebeurs voor leraren' (PhD-grant for teachers) was the start of a PhD-process that ends with this dissertation. The formal PhD-process is spread over some 11 years, but started much longer ago. Here, I want to express my sincere gratitude to many people who were instrumental during that journey.

It probably started with my father who from my early childhood onwards developed a desire in me to want to know how things really are. For anything discussed at dinner that was even just slightly unclear, he would say: 'We shall look it up!' and he would instantly proceed to do so. To this basic scientific curiosity, inspiring lecturers and professors at the Eindhoven University of Technology added a specific interest in environmental psychology and scientific rigor.

Leo Kemps as employer explicitly supporting my NWO-grant proposal, Prof. Harry Timmermans accepting my wish to act as promotor, and Prof. Agnes van den Berg joining the team for a while, helped me greatly in getting awarded the NWO-grant. Next, the actual PhD-research started.

During this process, I came to understand why many people warned me about time management when doing a PhD while also having a paid job. The PhD years saw continuous switches between the teaching job and the research project, which was not always the most efficient approach. Luckily, NHTV, later renamed Breda University of Applied Sciences, always supported me. From the academy management team, especially Leo, Debbie, Menno and Don were always constructive and interested in where things stood. Along the way, Jan Willem Proper, Paul van de Coevering, Pauline van Beusekom, Elly Khademi, Zhan Goosen and Joost de Kruijf helped by sharing mutual experiences in the PhD-process. At Eindhoven University of Technology, Theo Arentze and Soora Rasouli gave strong management and content support. Furthermore, on content, process, '*gezelligheid'* and collegiality, next to everyone at the unit, I want to thank most specifically Mandy, Astrid, Sophie, Merce, Valeria, Marielle, Samantha, Aloys, Peter, Tao, and Feixiong.

Many students have taken up elements of my research. I mention here specifically Baue Weemaes, Manon Vermeulen, Lola Ketelaars & Laurens Kuipers, Eva Slier, Paul Winkelmolen, Anouk Klein, Rene Wezenberg, Tom Duijkers, Willem Sprangers, Simone Klaassen, the 'Retrofitting'-class of 2018-2019 and Marieke Looman. Joran Jessurun, Frans van Hoesel, Frans Sijtsma and the partners at the municipalities of Eindhoven, Breda, Tilburg and 's Hertogenbosch were instrumental in the developing, implementation and administration of the very successful data collection. Many thanks to all of you!

Now, at the end of this journey, this dissertation and its defense is the final step. I am very honored to have in the defense committee Professor Terry Hartig, Professor Yvonne de Kort, Professor David Miller and Dr. Sjerp de Vries. Thank you for your valuable suggestions to improve the draft manuscript!

My promotor and co-promotor, Harry and Aloys, thank you for your help and the lengthy discussions we had. I have learned so much from you about research and methodology, and writing: being concise, specific, to the point, consistent.

Last, a PhD process is not just an academic exercise, nor does it happen in only one's academic life. I am very happy to have a great set of brothers, parents, parents in-law and sisters in-law and many great friends. Pieter-Marc, Maurice, Tom, mom, dad and Janneke, Vicki and Mick, thank you for your co-raising me. My dear friends Renske, Corine, Marike, Elise, Suzanne, Floor, Margriet, Steven, Bas, Gertjan, Maarten, Jorg and many more, thank you for sharing this journey with me; after 10 years still listening to me talking about cities, trees, grass and flowers; and simply being there in good times as well as less good times.

But most of all, dear Sabina, and my dear kids Luc, Emma and Casper: you have always supported me. The process took a little more time than we figured at the start and in those years we had some very joyful moments, for instance the NWO-grant being awarded, the very successful data collection and the finalization of the dissertation. However, you also had to deal with lesser days and some frustrations along the way, when things did not go as desired. However, the '*Profielwerkstuk*', as the kids have come to call it, is finished! I could not have done this without you, your help and most of all, your love. Thank you so much. I love you.

Robert van Dongen
Eindhoven, 23 May 2023

Summary

Restorative value of the urban greenscape: urban residential streets as restorative environments

Nature in cities has many important functions for human well-being, one of which is providing relaxation and escape from daily hassles through the beneficial psychological effects of recovery from stress and restoration of capacities to focus attention. Through these psychological effects, nature can support an urban environment to become a restorative environment. Studies on restorative environments have been conducted since the 1980's, and centered around two main theories, Stress Recovery Theory (SRT) and Attention Restoration Theory (ART), focusing mostly on large scale green spaces, such as forests, mountains, and large urban parks. Relatively few studies however, have been concerned with the urban greenscape: small scale nature in urban streets, such as grass verges, hedges or street trees. City dwellers encounter these natural elements on a regular basis, also when they may not actively seek them. Consequently, the urban greenscape may have a high potential to provide restorative effects to citizens. To date, however, it is unknown whether these restorative effects can be identified. The research question underlying this study therefore is: *What is the nature and strength of the relationship between different green elements and configurations of the urban greenscape and restorative value?*

Using municipal citizen panels in the four largest cities in the Dutch province of Noord Brabant, a sample of 4,956 respondents completed a stated choice task measuring the restorative value of virtual and hypothetical urban green profiles, and a rating task measuring restoration likelihood. The choice data are used to estimate a mixed logit model and the restoration likelihood data are used to estimate a regression model. Results indicate a significant relationship between restorative value and restoration likelihood on the one hand and specific elements, combined elements and different configurations of the elements within the urban greenscape on the other. Moreover, the models taking separate elements and configurations into account have better model fit than models using the percentage of the view covered by natural elements as a more holistic variable for the urban greenscape. Furthermore, the consistent results for restorative value and restoration likelihood provide support for attention restoration theory to apply to the experience of small scale nature in the urban greenscape.

The main findings point at a large restorative value and restoration likelihood of trees in general and large trees specifically, and that there is relatively low restorative value and restoration likelihood of grass and vertical green, limited interaction effects when combining different element types, and some influence of socio-demographic characteristics. Additionally, the results led to the definition of greenscape intensity, consisting of element intensity, related to the scale of the natural elements, and configuration intensity, related to the number or amount of natural elements. The influences of these intensities are to some extent interchangeable.

The findings of this study can be used as guidelines to better equip urban planning and design professionals to optimize the design of the urban greenscape at the detailed level of elements and configurations, to maximize the restorative effects of nature in cities.

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Chapter 1

Introduction

1.1 Background

Living in urban environments has become the predominant way of life for humanity. In 2014, more than half of the earth's population lived in cities. Forecasts indicate that by 2050 this percentage will have increased to 68% (UN, 2019). Although cities are dynamic and vibrant places to live, they also impose many mental and physical demands on their citizens resulting in different forms of stress. Citizens continuously have to stay alert to fast moving vehicles, protect their personal space and process a myriad of sensory input such as noise, smell and heat, which leads to environmental stress (Bilotta et al., 2019). Moreover, there are indications that social stress, caused by social processes, but resulting in similar physiological and psychological effects as environmental stress, is higher in urban environments than in rural areas (Lederbogen et al., 2011).

Opportunities for escaping from such stressors in urban environments are provided, in addition to other elements, by nature and natural elements. Large natural areas, such as parks, but also smaller elements such as grass strips, trees and gardens - called *urban green* - create spaces and places to recreate and relax (De Vries, 2010; Hartig & Kahn, 2016). Additionally, they offer shade, cooling (Imam & Banerjee, 2017) and clean air (Janhäll, 2015). Moreover, urban green contributes to city dwellers' well-being (Van den Bosch & Ode Sang, 2017) through increased neighborhood satisfaction (Zhang et al., 2017); faster recovery from surgery (Ulrich, 1984); stress reduction (Shuda et al., 2020; Ward Thompson et al., 2012); improved (mental) health, both self-reported and clinically diagnosed (M.P. White et al., 2013; WHO, 2016); less violence and aggression (F.E. Kuo & Sullivan, 2001; Shepley et al., 2019); and facilitating physical exercise and social interaction (A. Lee et al., 2015). Furthermore, there are indications that green environments have vitalizing and 'buffering' effects: after having stayed in a natural environment, people are more resilient and can endure more stressors (Egorov et al., 2020; Ryan et al., 2010).

Nature, thus, not only helps people to recover from stress as a curative effect, but may also build a preventive buffer against stress, and possibly against illness through "enhanced

immune functioning" (M. Kuo, 2015, p. 5). In addition to these general effects, research focusing on specific vulnerable groups in urban societies such as deprived communities (Ward Thompson et al., 2016), and the elderly (Kemperman & Timmermans, 2014), suggests that the effects of urban green on these groups are even stronger because they tend to have a higher need for urban green to facilitate their social interactions.

When looking for the mechanics behind nature's positive effects on health and well-being, review studies recognize four important pathways in which nature experience is linked to well-being (Abraham et al., 2010; Hartig et al., 2014; Krabbendam et al., 2020; Reichert et al., 2020): 1. Through the physics of the environment (e.g., cooling, air quality and water retention), 2. through physical health (e.g., walkability and leisure in relation to physical activity), 3. through psychological health (e.g., restoration from stress, vitalization), and 4. through the social environment (e.g., social interaction through meeting people and social leisure activities). These pathways promote well-being separately and in combination and interaction as shown in Figure 1.1. Of these four main pathways from nature to well-being, the psychological process of restoration is considered to be the most compelling explanation for the health benefits of nature (A.E. Van den Berg et al., 2019) and two main theories address such restoration: stress recovery theory (SRT) (Ulrich et al., 1991) and Attention restoration theory (ART) (S. Kaplan, 1995). Because of it restorative effects, a natural environment is considered to be a restorative environment (Berto, 2014) and as such a healthy environment. The rationale behind this is that - ceteris paribus - less stress directly leads to (feelings of) well-being. Furthermore, less stress, through physical health and the social environment, also indirectly supports well-being. First, less stress diminishes the risk of cardiovascular diseases (Cacioppo et al., 2016) associated with stress, thus increasing physical health and supporting well-being. Second, as stress can lead to inappropriate behavior (Arnsten et al., 2012), less stress positively affects the social environment. Psychological health thus directly contributes to well-being, and indirectly through physical health and the social environment. The interaction between physics of the environment and physical health is present in clean and cool environments being more inviting to be physically active and providing an environment more conducive to physical health through for instance clean air to breath and pockets of relatively cool urban spaces in hot summers, relieving the human body of heat stress.

Despite the growing evidence of the importance of urban green for human well-being, the last few decades have seen high development pressure on available green space in cities due to continuing urbanization, urban planning policy, and economic incentives. Creating high density cities has been considered beneficial in enhancing sustainability.
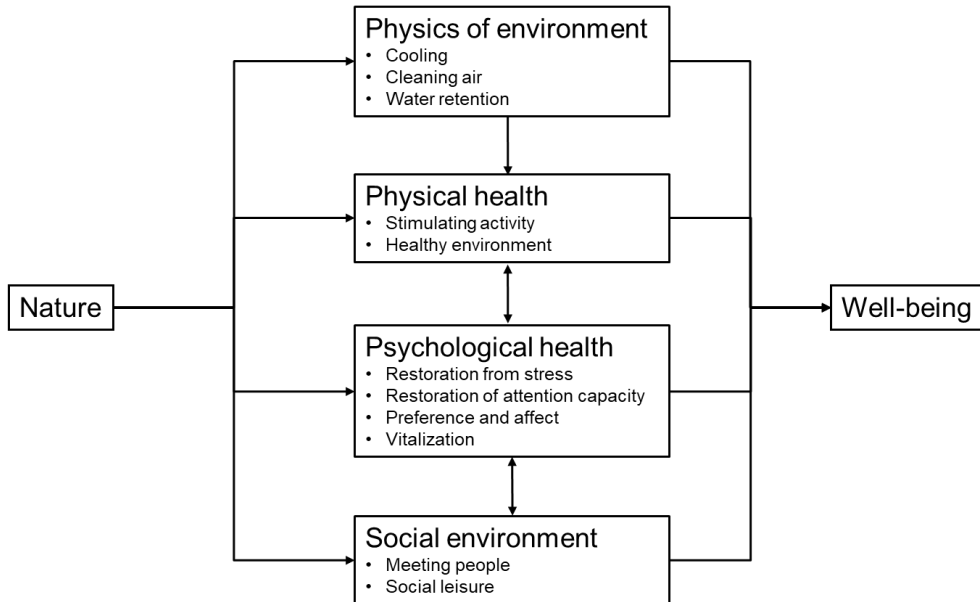
Figure 1.1 Pathways from nature to well-being

From the perspective of economic incentives, developing open green space into real estate will generate a substantial monetary profit to one or a few specific parties. On the other hand, developing or preserving urban green incurs a monetary cost and generates a mostly non-monetary benefit for other parties. Liberal market oriented societies will, therefore, more easily develop real estate than develop or sustain urban green. This means that taking care of a common good like urban green is typically a government task. Trends over recent decades for smaller government, more room for free market principles and urbanization and urban planning policies, therefore, put serious development pressure on urban green space.

Thus, while cities create a large need for the restorative effects of green, there is little space for it. The challenge, then, is to make the best use of the limited available space for urban green (Figure 1.2). This can be achieved by improving the restorative qualities of urban green and linking them to daily activity patterns, increasing the frequency with which citizens experience urban green environments. The link to daily activity patterns is supported by Dobson et al. (2021, p. 21), emphasizing *"… the importance of multiple everyday experiences of urban nature…"* in relation to stress reduction. This brings the focus to everyday living environments, in which many small-scale urban green elements, such as trees, grass strips and flower boxes, are found.

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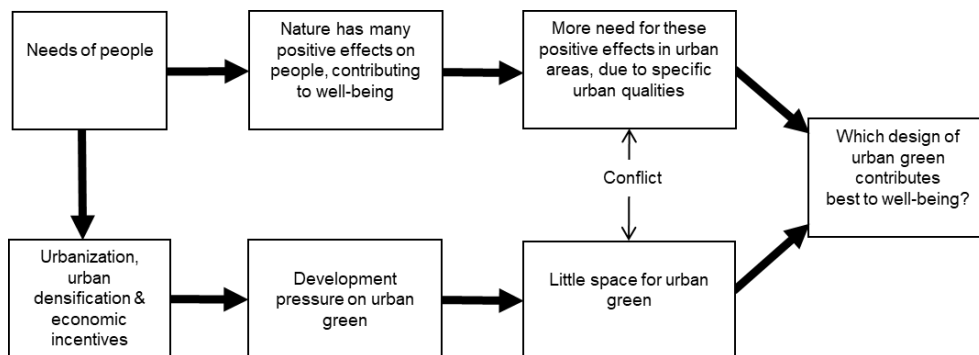
Figure 1.2 Context and relevance of current research

Although a lot is known about the positive psychological effects of nature in general as well as of large natural areas in cities, little is known about the influence of small-scale urban green elements on the micro level. The strength of the restorative effects of brief and unintentional encounters with small-scale nature in urban living environments is unknown. This PhD-project aims to fill this gap in our academic knowledge on the psychological restorative effects of small-scale green elements in everyday urban living environments. It focuses on psychological restoration as a pathway between nature and well-being in an urban context, where restorative effects are increasingly needed while only limited space is available for nature and natural elements.

1.2 Aim

The aim of this PhD research project is to establish the restorative value of separate green elements and their configurations in a street to better equip urban planning and design professionals in creating restorative urban green and making cities better places to live. It focuses on small-scale green elements in ordinary residential streets and the configuration of these green elements, i.e., how the green elements are placed in relation to each other and the rest of the urban environment. The elements and their configuration together are referred to as the *urban greenscape*. By improving the design of the urban greenscape, a better restorative quality and a higher frequency of experiencing restoration because of it can be achieved.

Currently, several dimensions and measuring scales of restoration exist. These different measures address different aspects and use different scales, complicating comparability and knowledge accumulation. Moreover, they focus on restoration, rather than restorativeness,

i.e., the restorative qualities, or restorative value, of environments. Some measures of restorativeness have emerged, such as perceived restorativeness (Hartig et al., 1997; Pals, 2012; McAllister et al., 2017) and restoration likelihood (Lindal & Hartig, 2015). These measures address an integral environment, and do not readily discern separate elements. This project aims to advance the field by moving towards a uniform measure of restorative value, which would facilitate improved comparisons across studies, as well as taking account of more detail by investigating restorative value at an element level. The following research question is addressed: *What is the nature and strength of the relationship between different green elements and configurations of the urban greenscape and restorative value?*

In order to answer this main research question, the following secondary research questions are addressed. First, to be able to answer the main research question, a means to accurately measure restorative value needs to be established. Research question 1 therefore is: *How to best measure the restorative value of an environment and its constituent elements and configurations?* Second, the restorative value of separate elements needs to be distinguished from the total restorative value of all elements together. However, it is as yet unclear whether decomposing the total restorative value of a greenscape into the constituent restorative values of the separate elements and configurations is possible. This leads to research question 2: *Are the presumably relatively small restorative values of elements and configurations in the urban greenscape discernable?* Third, so far, it is unknown to what extent distinguishing separate elements and configurations provides improved insight into the restorative value of the environment. This leads to research question 3: *Does taking separate elements and configurations into account lead to better predictions of restorative value than researching the urban greenscape as a whole?* Through this research, lastly, the aim is to establish whether the main theories on restorative effects of nature experience are also applicable to small and separate natural element in cities. Research question 4 is: *Can Stress Recovery Theory (SRT) and Attention Restoration Theory (ART) be extended to the urban greenscape?*

To answer these research questions, concepts such as well-being, urban greenscape and restorative environments need to be defined. Next, data need to be collected on the restorative value of the urban greenscape and its constituent elements, which can be challenging due to the dynamic use and appearance of the built environment. The environment looks different, for instance, when it rains or when it is sunny, or when it is busy or quiet. Research using a virtual environment may be a solution to tackle this challenge, as it is easy to keep those dynamic aspects constant. In this PhD project, data were collected through a survey administered in the four largest cities of the Province of Noord Brabant in the Netherlands. In the survey, respondents were invited to judge the restorative value of urban greenscape

designs, represented in virtual environments. A stated choice experiment was used to estimate the relationship between urban greenscape design, represented as profiles of greenscape attributes, and its restorative value. In addition, a regression analysis on the relationship between urban greenscape design and the measure of restoration likelihood (Lindal & Hartig, 2015; Van den Bogerd et al., 2018) was conducted, as it is of interest to examine to what extent the measure of restorative value can be linked to other established measures of restorativeness, commonly used in restorative environments research. Analysis of both provided knowledge on the separate restorative values of the elements and configurations.

1.3 Outline

This thesis reports the design, implementation and findings of the study on the restorative value of street-level green elements and configurations in urban areas. A wide range of effects of urban green has been studied at length, but a knowledge gap still exists regarding the restorative value of small-scale elements in urban streets - the urban greenscape. This PhD-project addresses this topic because the urban greenscape has the potential to significantly contribute to psychological restoration, due to its easy accessibility and the high contact frequency involved.

Chapter 2 examines the literature on restorative effects of nature - and urban nature specifically - providing the theoretical framework underlying the project and the study. There are two main psychological theories on restorative environments and psychological processes behind restoration, rooted in concepts such as well-being, stress, stress recovery and attention restoration. The chapter summarizes the main theoretical lines and empirical evidence and evaluates the current state of the art regarding research methodology. Scientific gaps in content and methodology are identified: limited attention in the academic literature is paid to small-scale urban green elements in residential streets, and studies tend to have methodological limitations in design, sampling and analysis.

Chapter 3 builds the argument that the urban greenscape has the potential to support the well-being of citizens through psychological health by allowing frequently experiencing restorative effects generated by small-scale urban green elements in daily life. The chapter derives the research questions and conceptual framework, aimed at investigating the nature and strength of the relationship between different green elements and configurations of the urban greenscape, and restorative value. A novel approach in researching restorative value is

proposed by using choice experiments, a method more common in urban planning than in environmental psychology, as a way to measure the restorative value of a greenscape design and allowing the decomposition of overall restorative value of a greenscape design into the restorative values of the constituent elements and their configuration. Additionally, the measure of restoration likelihood is used (Lindal & Hartig, 2015) as a measure of the level to which a respondent feels the environment would allow psychological restoration and improve cognitive performance. Aspects of psychological affect and perceived restorativeness accompany it. The measure of restoration likelihood is closest to a unidimensional measure currently in use. In order to consider separate elements, the main natural elements and configurations of the urban greenscape are defined. The chapter further discusses the advantages and disadvantages of different ways of presenting urban greenscape environments in terms of the level of realism of experiencing an actual environment or a representation of it, and studying a real or a fictional environment. With the rapid advancement in computer capability a high level of realism can be achieved when using virtual representations. The chapter presents using virtual environments as the methodology chosen for this PhD project.

Chapter 4 describes details of the operationalization of the data collection in four cities in the Netherlands. This data collection was set up in close collaboration with the respective municipalities and used a virtual environment for a choice and rating task to measure the restorative value, and restoration likelihood of the urban greenscape respectively. Further data was gathered on respondents' opinions about the current greenscape design in their city and neighbourhood, and their socio-demographic background. Close to 5,000 respondents completed the questionnaire, providing 69,384 data points used to estimate the restorative value of hypothetical greenscape designs in the choice experiment, and 39,648 ratings of the restoration likelihood of the same greenscape designs.

Chapter 5 presents the results of the analyses of the choice and rating tasks, with modelled estimates of restorative values of the greenscape elements and configurations and their restoration likelihoods respectively. Specific results and general patterns are presented.

Chapter 6 discusses the main findings of the research project, derives policy implications and reflects on its limitations. The chapter ends with suggestions for future research.

Chapter 2

Definitions and theoretical framework:
restorative environments

2.1 Introduction

Rapid urbanization puts more people at the risk of experiencing environmental stress, which is detrimental to well-being. At the same time, urbanization tends to decrease the opportunities to experience the beneficial effects of nature on well-being, because of pressure on the limited available space for nature in cities. In this context, R. Kaplan & Kaplan (1989) introduced the concept of *restorative environments* to indicate that particular environments trigger processes of psychological restoration. Such restorative environments are means to restore from and potentially prevent stress in daily urban life. Urban green is argued to have the potential to induce such restorative processes.

The chapter starts with two different scientific perspectives on restorative environments: environmental psychology and urban planning and design. Central in research on restorative environments is the notion that restoration from (environmental) stress is beneficial to well-being. The concepts well-being and stress are addressed in the next section, after which the two main theories about restoration and restorative environments and their empirical support are discussed. Limitations in the current body of knowledge on the restorative value of urban green are identified, arguing that there is a gap in knowledge about the restorative value of small-scale urban green in residential streets.

2.2 Environmental psychology & urban planning and design

Restorative environments, and urban green in particular, can be analyzed from different perspectives, evidenced by the fact that urban green has been the subject of study in different fields of academic research, including urban planning and design, and environmental psychology. Urban planning and design are primarily concerned with the physical environment of the city. They aim at advancing knowledge about creating cities that are pleasant and healthy places to live and work, and enable citizens to realize their needs and desires.

Urban planning and design have developed theories, concepts and strategies to develop and revitalize (urban) environments that reflect the preferences of different segments of the population and other stakeholders, while simultaneously achieving a set of societal goals and objectives, related to the economy, welfare, health, social cohesion, and the environment. These disciplines aim at planning and designing environments that increase the well-being of its citizens.

Environmental psychology is a sub-field of psychology that studies the interplay between individuals and their environment, both natural and man-made. Knowledge about environmental psychology that relates to the built environment can help urban planners and designers creating environments that improve psychological health and, therefore, human well-being, for instance by preventing or reducing stress. Stress may be caused by different factors, such as work pressure, lack of income, health concerns and personal relationships. However, the built environment itself may also induce stress. Such environmental stress may be caused by stressors in the urban environment, such as noise, crowding and danger, leading to psycho-physiological reactions of the human body. Stress may (in the long term) be detrimental to health and well-being as reflected in, for instance, higher risk of physical and psychological ailments such as cardiovascular diseases (Kivimäki & Steptoe, 2018) and anxiety (Uchino et al., 2007). The reduction or prevention of (environmental) stress will, therefore, benefit citizens' well-being.

2.3 Well-being and stress

In order to examine the potential of urban planning and design to improve well-being by reducing or preventing stress, insight in the concepts well-being and stress is needed.

2.3.1 Well-being

In defining well-being, an important distinction has been made between *objective* and *subjective* well-being (e.g., Diener & Suh, 1997; Ettema & Schekkerman, 2016). *Objective* well-being (OWB) relates to the use of official statistics or indicators that measure the well-being of a group of people or a country. Often, objective well-being includes at least a health perspective, an economic perspective (being able to satisfy wants and needs), and a social perspective (position in society, based on social indicators). In the context of the built environment one could, for example, think of low air quality, measured as the level of sulfur dioxide in the air (Perlaviciute & Steg, 2019), mostly caused by carbon fueled power plants and industry emissions; the number of traffic accidents per capita, or unemployment rates.

Regarding objective well-being measures of beneficial health effects of urban green, several epidemiological studies indicate a link between availability of nature and several health indicators, such as reduced prevalence of cardiovascular diseases (strongly related to stress), diabetes and mortality (M. Van den Berg et al., 2015; WHO, 2016). However, causality is often difficult to establish, also because of the complexity of urban environments, where several potential causes are spatially correlated (e.g., less traffic related air pollution and urban green space (Rugel & Brauer, 2020)).

In contrast to such objective well-being, *subjective* well-being (SWB) refers to how individuals assess their perceived health, job, living environment, social relations, achievement of life goals, etc. SWB distinguishes between long term life satisfaction and short term positive or negative affective responses (Diener, 2009; OECD, 2013). Several scales aim at measuring aspects of wellbeing (for instance for the affective responses, PANAS, Watson et al., 1988) or a more integrated measure of wellbeing (for instance WEWMBS, Tennant et al., 2007). Well-being thus involves (but is not equal to) psychological aspects. The focus of this study is psychological health as one of several pathways linking nature to well-being (see Figure 1.1). This pathway contributes to well-being directly as improved psychological health leads to improved well-being. Moreover, improved psychological health supports (objective) physical health (Kemp & Quintana, 2013) and one's social environment through more social and appropriate behavior , thereby also indirectly contributing to well-being (Arnsten et al., 2012).

2.3.2 Stress

Stress responses in the human body and mind are normal human functions and serve a clear purpose. When in danger, stress responses quickly prepare the human body for action. When the danger is over, the system slowly returns to normal (Cacioppo et al., 2016). Acute stress should be distinguished from chronic stress (i.e., being under the influence of a continuous stressor). Chronic stress is believed to be more detrimental to psychological health than acute stress (Uchino et al., 2007) and chronic stress experienced in the past increases the risk of a more negative stress response to current acute or chronic stress (Epel et al., 2018).

Stress derived from the environment is called environmental stress. Cities are known for generating high activation levels, as they are also the source of an abundance of environmental stressors such as noise, pollution, crowding and danger, in addition to social stress, due to high social expectations, uncertainty and large socio-economic differences, which are more prevalent in cities (Bilotta et al., 2019; Lederbogen et al., 2011). By their very nature, these stressors in the urban environment are continuous, presenting an increased risk of chronic stress. Continuously filtering out stressors (e.g., noise) and scanning the

environment (e.g., safety) involves the activation of mental capacity that cannot be used for other purposes. Consequently, the mental capacity may become depleted or insufficient for the continued filtering and scanning of environmental cues, resulting in environmental stress. The same process is also the basis of theories of stimulus overload resulting in mental or directed attention fatigue (DAF) (S. Kaplan, 1995). DAF suggests that directing attention requires continuously blocking out different competing sensory inputs, which uses and later depletes the capacity of the pre-frontal cortex to perform this filtering function. When sensory input is no longer or less efficiently filtered, too much information reaches the brain, leading to overload, and the inability to focus attention (Arnsten et al., 2012; S. Kaplan, 1995; S. Kaplan & Berman, 2010). Moreover, continuous stress does not only deplete the mental capacity to filter sensory input and focus attention, it also depletes the capacity for monitoring error, testing reality, regulating emotions and inhibiting inappropriate actions. This potentially results in more primal and impulsive behavior, which quite often is considered socially unwanted (Arnsten et al., 2012; S. Kaplan & Berman, 2010) and negatively affects the social environment.

2.4 Theories on restorative effects of nature and urban green

The psychological process of recovery from stress and mental fatigue is believed to be the most compelling explanation of the beneficial effects of nature, and urban green, on psychological health (A.E. Van den Berg et al., 2019). This section discusses the two main theories, their limitations and criticism, and their empirical support, leading to the formulation of gaps in the current body of knowledge related to these theories and the restorative effects of nature and urban green.

2.4.1 Restoration: stress recovery and attention restoration

Two main theories address the restorative effects of nature: first, the theory on recovery from stress, Stress Recovery Theory (SRT) (Ulrich, 1979; Ulrich et al., 1991), and second, the theory on restoration of mental capacities, Attention Restoration Theory (ART) (S. Kaplan, 1995). Both theories address partly interlinked mechanisms in the brain. While SRT addresses the effect that nature has on allowing the mind and body to recover from stress, ART is concerned with the mental capacity to focus attention, which diminishes during demanding tasks, requiring restoration in order to function well again.

SRT states that nature allows the human system to relax, thereby restoring physiological, emotional and mental capacities after stress (Ulrich et al., 1991). The causes of nature affording such stress recovery are hypothesized to be the evolutionary advantage of

automatically and effortlessly being able to understand one's natural environment for danger and safety. In SRT, restoration is defined as positive changes in psychological and emotional states, and the accompanying physiological systems after experiencing stress. The changes in emotional states are called affective responses, which are distinguished into positive affect (such as excitement and happiness) and negative affect (such as anger and nervousness). Positive changes may in turn lead to improved cognitive functioning: In SRT, the affective responses to an environment are considered to happen before cognitive functioning is affected (Hartig et al., 1991). Possible restoration of mental capacity and attention is therefore considered a secondary effect resulting from stress recovery. SRT is thus centered around stress and the recovery from stress in relation to the restorative value of an environment. Measuring affective responses and stress levels are central to validating this theory.

Some points of criticism regarding SRT have been brought forward. First, Joye and Van den Berg (2011) state that mostly researchers mention or imply *unthreatening* natural environments when linking nature to stress recovery. Second, S. Kaplan (1995) argues the neglect of the influence of consciously choosing to be in an environment and its potentially stressful stimuli, such as joining a music festival, which can be considered stress relieving for some, while stressful for others. In addition, the role of cognitive processes such as ordering information, potentially preventing stress, is undervalued (Joye & Van den Berg, 2011; S. Kaplan, 1995). Joye and Van den Berg (2011) elaborate on that role of cognitive processes, proposing that cognitively processing a natural environment puts less burden on the brain leading to more positive affect and less negative affect. This thus suggests a switch in order from primarily the affective response, to primarily a cognitive response. Such criticism has fed the development of ART.

Seminal work on developing ART was conducted by S. Kaplan (1995). ART states that after a period of focused attention (like listening to a lecture or working on a specific task) the capacity to focus attention diminishes and needs to be restored. Natural environments are assumed to be highly conducive to restoration because they provide a sense of *being away*, offer overview and mental challenge (*coherence)*, are compatible with needs and preferences (*compatibility*), and are deemed fascinate (*fascination*). First, natural environments allow a person to have the feeling of being away, which means being away from a task or environment that requires focused attention (S. Kaplan, 1995; Joye & Van den Berg, 2019). However, being physically away may not be enough because one can still be focused on the task that was conducted before. For this reason, being away is sometimes split into being physically away (*novelty*) and being mentally or psychologically away (*escape*) (Pals, 2012).

Second, an environment must have sufficient mental challenge and offer overview to prevent the mind from wandering back to the previous subject of attention. A 'boring' view is not helpful. Being able to have an overview of an environment gives a sense of control and requires less mental capacity to keep track of the environment, supporting restoration. In the context of the restorative value of nature, overview is less a 'standard' attribute of nature as it greatly depends on the type of nature.

Third, the environment should be compatible with current needs and preferences (S. Kaplan, 1995). What is needed is an environment that allows one to do things 'comfortably and naturally' and vice versa; what you do *'is appropriate to the setting'* (S. Kaplan, 1995, p. 173). An environment that is compatible with the desired activity offers fewer distractions for that activity, allowing the mind to work less hard, or even rest and replenish. Natural environments are considered very compatible with the need for restoration. Lastly, natural environments are considered to offer fascination in the sense that they can effortlessly capture attention (S. Kaplan, 1995).

Fascination is defined as involuntary attention: one automatically and effortlessly pays attention to things when they are interesting. Natural elements fascinate the mind without the need to focus, and thereby allow restoration of the depleted focused attention capacity. The reason for this effortless fascination is sought in the evolutionary advantage of being able to perceive and understand the natural environment automatically as argued in the biophilia hypothesis (Kellert & Wilson, 1993; Wilson, 1984), also deemed applicable to SRT. It states there is an innate preference for natural environments due to evolutionary processes. The main point of *biophilia* is that humans have adopted their lifestyles to urban settings only relatively recently. Evolution has for millions of years taken place in natural settings, where survival, and hence passing on genetic information, depended on knowledge about safe surroundings and acknowledging the value of natural features in orientation, shelter, safety, food and drink. This line of reasoning could help explain restorative effects. Moreover, and specifically for ART, S. Kaplan (1995) refers to evolutionary advantages of getting fatigued when focusing attention: being able to focus attention by suppressing distracting stimuli for a prolonged period of time makes one less observant of one's surroundings and, hence, more vulnerable to sudden (dangerous) external influences (like an attacking animal or neighbor). Kaplan argued that humans therefore evolved to 'automatically' pay attention to our environment, which was only nature. This automatic attention became effortless attention, allowing the mechanisms suppressing distractions to rest and restore.

In short, ART, considers the replenishing of the capacity to focus attention as the primary effect of restoration. Focusing attention requires mental resources, as it requires the mind to separate stimuli that are considered relevant, from stimuli that are considered irrelevant and distracting. When those mental resources are depleted, the capacity to filter will decrease and the mind will become flooded with too much information, leading to stress and negative affective responses. In contrast with SRT, ART thus states that possible recovery from stress is therefore considered a secondary effect resulting from restoration of mental attention capacities. Measuring focused attention and (resulting) cognitive performance are central to validating ART.

Some criticism of ART has been expressed in the literature. First, regarding the evolutionary origins of biophilia, there are some aspects of biophilia that are still under debate, such as the fact that there is also scientific evidence of fear of nature (biophobia) (Patuano, 2020; A.E. Van den Berg & Konijnendijk, 2019), which would be the opposite of biophilia. Note the similarity with criticism on SRT and the focus of *unthreatening* nature. Moreover, the influence of culture could oppose innate effects. Second, one could argue that regarding 'fascination', restorative effects are derived from the 'effortless' part in the definition, rather than the 'fascinating'. Possibly, the 'effortless' is about 'familiarity', and that evolution has hardwired natural environments as 'familiar'.

Some further open questions and criticisms have been formulated by Joye and Dewitte (2018) and are briefly summarized as follows. First, the term 'restoration' presumes a base level to which attention capacities can be restored. There are however indications that there are 'restorative' effects beyond such a base level, and also for non-fatigued people, by strengthening psychological resilience (Dzhambov et al., 2019) and through vitalization (Ryan et al., 2010). Such effects would further increase the potential beneficial effect of nature experience. Second, ART not only addresses attention restoration, but rather restoration of cognitive performance in a broader sense, *including* attention capacity. Cognitive performance measures also include performance such as memory recall, and logical reasoning. Third, the distinction between soft fascinating and hard fascinating is unclear. Some environments can be fascinating in a more dramatic way, such as a sporting venue during an important match, and are likely effortlessly fascinating in its own way, but not necessarily supporting a wandering mind, allowing deeper reflection. This distinction between soft and hard fascination can also be related to the previous suggestion about 'familiarity'.

2.4.2 Empirical evidence

In this section, empirical evidence of SRT and ART in relation to different environments is reviewed. Considering the nature of SRT, empirical work distinguishes measures of affective responses to stress and measures of (changes) in subjective or objective stress levels. The review of empirical evidence will start with these two aspects of SRT. Next, empirical evidence on ART will be evaluated. It concerns restoration linked to restorative properties of an environment, seen as a main driver of cognitive performance, such as performing mentally demanding tasks, well-functioning memory and sustained attention. Review studies and a selection of additional recent empirical studies are presented and measures of the (perceived) restorativeness of environments are discussed.

SRT - Affective responses

McMahan and Estes (2015) reviewed 32 studies published between 1979 and 2012 on affective responses, such as feeling excited, ethousiastic, inspired or irritable, nervous or scared, to the experience of natural environments. They concluded that these studies demonstrate that experiencing natural environments leads to moderately more positive affect and relatively little less negative affect, regardless of whether the natural environment is considered 'wild' or 'managed', but note that the level to which respondents may consider an environment as wild or managed also depends on one's perspective; moreover, an environment intended to suggest 'wild' can for some be considered quite managed. Half of the reviewed studies measured responses to real environments and the other half to virtual environments. Experiencing real natural environments showed larger positive effects than experiencing virtual natural environments. An important limitation of the included studies is the over-representation of relatively young age groups as indicated by an average age of the respondents between 20 and 28.5 years. Moreover, of the reviewed 32 studies, 12 had a sample size of 50 or less and 22 of 100 or less, seriously reducing the confidence levels of the results.

Addressing the limitations of sample size and age range, McAllister et al. (2017) examined affective responses of a convenience sample of 220 Australians to randomly assigned virtual contact (video) with wild nature, urban nature, and an urban built up environment. Subjects were between 18 and 75 old (average 49), and 72% was female. Measures of positive affect were significantly larger for the wild nature environment than for urban nature and urban environments and measures of negative affect were significantly smaller for the two nature environments than for the urban environment, which is in line with McMahan and Estes' review (2015), except for the differences between wild nature and managed nature. McAllister et al.

found higher positive affect for wild nature than for urban nature, but no significant differences for negative affect between wild and urban nature, while the review did not find differences between wild and managed nature. This signals that when comparing natural with urban settings, the differences are quite pronounced, but depending on approach, comparing *within* natural settings is more challenging and tends to yield no, mixed or subtle differences. A shortcoming of McAllister et al.'s study is the fact that measures were only taken after the video intervention. Therefore, the *change* in affective states is not measured, complicating drawing conclusions on causality.

Alternatively, Tyrväinen et al. (2014) measured affective state both before and after 77 Finnish participants viewed either a forest, park or city centre while seated in the actual outside environments and walking through the environment. Results indicated a significant difference in positive affect between the two nature and the urban settings but no significant difference between forest and park, which supports the suggestion that, at least for positive affect, differences within nature settings may depend on the rest of the frame of reference. However, for negative affect, the park and urban environment showed no significant difference, while the forest did. McMahan and Estes's review plus these two studies all three suggest that the effects of nature experience are more pronounced for positive affect than for negative affect, indicating that nature experience is more effective in improving positive emotions, than reducing negative ones.

A further laboratory study that compared an urban environment with three natural environments differing in management level (park, tended woodland and 'wild' woodland) was conducted by A.E. Van den Berg et al. (2014). The study first induced stress through a scary movie, and then showed a simulated virtual walk of approximately 6.5 minutes through a particular environment to 102 participating UK university students. Affective states as a measure for stress recovery were measured using POMS and a self developed scale of 'restorative state' before and after the stress inducing movie and after the virtual walk. Subjects were randomly assigned to watch one of the four different virtual walks. Findings indicate for all measures that subjects who experienced a natural environment showed significantly more stress recovery. However, no significant difference was found between the three natural environments, which is in line with the argued difficulty of measuring differences between natural settings, rather than between urban and natural settings. The authors discussed the role of attitude and differences in needs (e.g., a stronger stress response to the movie leads to a higher stress level and larger stress recovery potential) as possible additional influences on stress recovery. The researchers concluded that restoration not only depends on the physical environment, but also on individuals' needs and perception of the environment.

Of the so far discussed studies, McMahan and Estes (2015) did not distinguish between studies which included some form of physical activity (e.g., walking) and which did not, McAllister et al. (2017) and A.E. Van den Berg et al.(2014) did not include any physical activity, while Tyrväinen et al. (2014) did. Zooming in on this potentially confounding influence, Kinnafick and Thøgersen-Ntoumani (2014) measured, both in a laboratory setting ($n = 40$) and in a real environment ($n = 30$), the influence of the environment on positive and negative affect among university staff and students of an urban and a natural environment, depending on whether they were walking or sitting. The laboratory setting showed a significant decrease in negative affect of viewing nature and an increase in positive affect of walking (on a treadmill). The real environment setting found the most significant influence for activity. Walking had more positive effects than sitting, which may have been caused by the relatively cold weather during the observations, which can make sitting outside unpleasant. This suggests an interaction between physical activity and natural environment, strengthening the positive affective responses of either or both. The authors conclude that physical activity, which is supported by natural environments, may be the main cause of positive affective responses rather than the natural environment itself. This was also the starting point for a systematic review by Bowler et al. (2010), addressing the question whether there is sufficient evidence of benefits to health (using different measures for affective, attention and physical health outcomes) of experiencing natural environments beyond the provision of an encouraging environmental setting for healthy behavior, such as physical activity. The synthesized findings of 25 studies suggest that there is such evidence for the affective outcomes.

It seems current research makes a variety in choices between different dimensions and methods: type of environments (urban vs natural or within natural); activity (as part of the experimental treatment or not); type of experience of the environment (real vs virtual); application of pretest and posttest measurements or not.

SRT - Stress

A second approach to measure stress recovery is by examining stress levels. Because the human body physically reacts to stress, it is possible to measure physiological responses as indicators of stress and stress recovery. Studies relying on physiological stress reactions apply measures such as, for instance, heart rate (e.g., Park et al., 2010; Stigsdotter et al., 2017), cortisol levels (e.g., Jiang et al., 2014; Roe et al., 2013; Tyrväinen et al., 2014) and skin conductance (e.g., Hedblom et al., 2019; X. Wang et al., 2016). Studies using physiological measures of stress recovery tend to show that nature experience leads to lower physiological stress levels. However, this is not consistent across all studies and measures. For instance, no significant difference was found between urban and nature settings in cortisol levels by

Tyrväinen et al. (2014) and heart rate measures by Stigsdottir et al. (2017). In the latter study, this may be explained by their choice of a historic city centre as the 'best case' urban setting, which may possess other restorative qualities than nature, and thereby more restorative qualities than a general urban setting. Alternatively, studies choose 'worst case' urban settings such as industrial estates or busy traffic infrastructure. The choice of contrasting environment thus introduces variation in characteristics other than the environment being 'urban' or low on green, which may affect measures. Moreover, Jiang et al.'s (2014) findings indicated that physiological measures only showed improvement in stress level for males, not for females. However, there is no theoretical backing for this finding nor has it been shown in other research. And, in contrast, Roe et al. (2013) found that females tend to experience higher stress levels (as measured by cortisol levels) if they live in neighborhoods with little neighborhood greenspace, than males do.

Shuda et al. (2020) reviewed 12 studies that were conducted between 2010 and 2019, plus Ulrich et al.'s seminal study, on the influence of nature exposure on stress levels, measured through perceived stress and/or physiological stress markers. The seven reviewed studies using physiological stress measurements, one of which also used perceived stress levels, all clearly found that the experience of nature led to lower stress levels. Alternatively, Bowler et al. (2010), came to the conclusion that there are no convincing physiological effects after nature experience relative to the experience of non-nature environments. They additionally note that this does not imply there is no effect. There are indications that *during* the nature experience, such physiological effects are present suggesting that repeated nature experience may induce positive long term effects.

Besides physiological measures, respondents may be asked to subjectively self-report their stress level and opportunities to recover from it. Shuda et al.'s review (2020) included six studies using such perceived stress measures. Five out of the six found that the experience of nature led to lower perceived stress levels. The sixth study, which did not find any support, analyzed perceived stress levels of identical twins in relation to the level of available green in neighborhoods. Working with identical twins allows avoiding the influence of different biological predispositions (Cohen-Cline, et al., 2015). No significant difference was found between the two individuals of the identical twin, when comparing their perceived stress levels, indicating that biological predispositions may actually play a role. Nevertheless, Shuda et al. (2020) concluded there is strong evidence of stress restorative effects of nature. As the review allowed studies with and without urban-natural comparison, with and without activity, both real and virtual environments, and with and without pre- and posttest measurements, comparison

on some of those dimensions was complicated, but deemed possible, making the researchers conclude that socio-demographic factors and physical activity also play a role.

An additional study using a combination of both perceived stress and physiological stress markers before and after spending time in either a forest, park or indoor exercise facility was conducted by Y. Chang, et al. (2019). Most significant, lower cortisol and perceived stress levels were found for the forest environment. Spending time in the park setting led to significant improvements in three of the four measured factors of perceived stress for the park setting, while visiting the indoor exercise facility resulted in a reduction of only the two negative items (*demands* and *worries*) in the perceived stress questionnaire. Findings are in line with Shuda et al.'s review, less so with Bowler et al's., but sample bias may have influenced the results because the study recruited 35 participants per site from visitors to the site. The respondents were by definition inclined to visit the site and therefore not randomly assigned.

ART - Cognitive performance

Focused attention and (resulting) cognitive performance are central in ART. Bowler et al.'s review (2010) found no significant pooled effect on attention measures for exposure to nature when using pre- and posttest measures. However, Bowler et al's review included several different outcome measures, of which only three included studies were concerned with attention measures. Two other reviews specifically looking at measures on cognitive performance covered 31 studies from the period 1991 to 2012 (Ohly et al., 2016), and 42 studies from the period 2013 to 2017 (Stevenson et al., 2018) respectively. Both reviews show support for ART: experiencing natural environments improves cognitive performance, independently of how it is measured. Studies on the effect of nature on cognitive performance usually first induce stress, e.g., by showing a scary movie (e.g., A.E. Van den Berg et al., 2014) or inducing mental fatigue by applying a mentally demanding task (e.g., Berto et al., 2010; Hartig et al., 2003). Next, subjects are asked to complete a cognitive task (such as a Rubick's cube, Sudoku puzzle, or memory task), or subjective evaluations of the respondents' restorative states, serving as a baseline. As cognitive task, the reviewed studies generally administered sustained attention tasks, directly related to the restoration of attention capacity, and memory and complex logical reasoning tasks. After establishing the baseline, subjects are usually randomly split into two groups each receiving a different treatment (such as a walk in the forest for one group and a walk through an urban environment for the other) and asked to repeat the cognitive task, or evaluation of restorative state.

Zooming in on a specific type of cognitive performance, sustained attention findings show that after being in nature or viewing pictures of natural environments, respondents tend to perform better in sustained attention tests (e.g., Berman et al., 2008; Berto, 2005). Even a very short break for viewing natural environments between two sustained attention tasks has a positive attention restorative effect (K.E. Lee et al., 2015). However, not all studies show clear and consistent results. For instance, Berto (2005) used a straightforward experimental design with a mentally demanding task after which the participating 32 Italian university students viewed a series of 25 photos of either natural and natural-agricultural landscapes, or urban and industrial landscapes. After that, the same sustained attention task was performed. Differences between reaction time and correct/incorrect reactions before and after the viewing intervention indicated improved sustained attention (the applied test was deemed insensitive to learning). The study found *within* each subgroup significant improvement on three out of four indicators (except for the number of incorrect answers) after viewing the 'restorative environments', but not after having viewed the 'non-restorative environments'. However, no significant differences were found *between* the two subgroups, whether before viewing (which would be expected), or after viewing either a restorative or non-restorative environment. This could be due to the small sample size. Neilson et al. (2020) replicated the study using some improved measurements, such as adding a third control group, viewing geometric patterns, and found slight but not significant improvements in performance on the applied sustained attention task for both the nature viewing group and the control group. The group viewing urban environments showed a negligible and non-significant decrease in cognitive performance. Therefore, the results of Berto's study were not replicated and no significant evidence supporting ART was found here.

Besides focused attention tasks, memory has been considered in other studies. For instance, Bratman et al. (2015) randomly assigned 60 respondents from a student age population to two groups exposed to respectively a 'nature' and 'urban' walk, and checked whether the subgroups had similar socio-demographic characteristics. Memory performance measures were taken before and after the intervention. Results showed that memory performance significantly increased after the 'nature treatment', while it did not after the 'urban treatment'. However, on an also taken measure of focused attention, the difference in performance was not significant (at $p < .05$) between the two conditions. Hence, in this study, mixed empirical support for ART was found and cognitive performance was not as independent of measure taken, as argued by Ohly et al. (2016) and Stevenson et al. (2018). Overall though, studies show that the cognitive performance of the nature group after the treatment significantly exceeded the performance of the urban group, which validates ART.

Looking at the literature base for both SRT and ART, empirical findings tend to indicate restorative effects of natural environments. However, the strength and significance of the effects also depend on what is being compared and how well possible other factors are taken into account. Such socio-demographic characteristics, and different types of activity, were shown to be relevant. Furthermore, the more similarity between the environmental settings under research, the more difficult it is to adequately distinguish significant effects, thus requiring more control of 'other' factors, and more detail in the differences in the environment. Moreover, methodological aspects, such as using real or virtual environments, and sampling, play an important role. A critical discussion of methodological aspects of the current literature base is provided later in this chapter.

Despite at times mixed findings and possible criticism of SRT and ART, both theories continue to provide a useful framework and having this framework allows addressing some of the theories' limitations and open questions. Moreover, both theories explicitly consider an important role of the physical environment in achieving restoration. SRT acknowledges that nature experience has stress restorative effects and ART explicitly links restoration of attention capacity to qualities of the (urban) environment. Therefore, research based on both theories also takes the qualities that make an environment conducive to stress recovery and attention restoration as the object of study. This relevant interplay between the disciplines of environmental psychology, and urban planning and design centers on the restorative quality of environments.

Restorative quality of environments and perceived restorativeness

Additional to measuring restoration through affective responses, physiological or perceived stress levels and cognitive performance of humans, studies have relied on measures of the restorative qualities of environments, i.e., the restorativeness of an environment. It addresses the extent to which citizens assess or perceive the environment to be restorative rather than citizens' actual stress or attention restoration. Perceived restorativeness is an often used indicator of *actual* restorativeness, despite only relatively few studies showing significant and substantial correlation with cognitive restoration (measured through task performance) and affect (e.g., Hartig et al., 1991; Marselle et al., 2016).

Research results on perceived restorativeness of environments showed that natural environments tend to be perceived more restorative than non-natural environments. Two examples are Pasini et al. (2014) and McAllister et al. (2017). Pasini et al. (2014) concluded, based on the use of the Perceived Restorativeness Scale (PRS) among 330 Canadian and Italian participants, with a mean age of 23.5, that natural environments were perceived more

restorative than urban environments. Of different urban environments, industrial zones scored the lowest on perceived restorativeness. Findings were invariant across countries and gender, suggesting limited influence of culture, which would be expected if indeed evolutionary origins of the restorative effects are at play. McAllister et al. (2017), besides the previously discussed affective measures, also investigated the perceived restorativeness of a forest environment, park environment and an urban environment using PRS (n = 220). Wild nature (forest environment) was considered significantly more restorative than urban nature, which was considered significantly more restorative than the urban environment. The difference between the two nature environments was much smaller than the difference between them and the urban environment. This finding is similar to the various other discussed studies on SRT and ART. Moreover, the analysis showed that the level of restorativeness acted as a mediator between nature and affect, which can be considered supportive of ART (rather than SRT).

These studies, however, compare natural environments with urban environments, which are strongly contrasting. When the object of research is differences in restorative qualities *within* urban environments, the contrast is smaller and differences are expected to be similarly smaller. A.M. Weber and Trojan (2018) reviewed 39 studies on the restorative value of nature within urban environments and show that small differences can be distinguished. They found that natural elements increase the restorativeness of urban environments. Additionally, they found that urban scenes can also have a restorative value, mostly in relation to cultural, architectural and leisure opportunities, suggesting that manmade elements and environments can also be considered restorative. Including such man-made elements in urban park environments, X. Wang et al. (2016) applied PRS in a study among 140 Chinese university students comparing movie clips of an urban road and six urban park scenes varying in openness, presence of other people and paved versus natural surface. Findings indicated that perceived restorativeness was significantly higher for the scenes with more natural elements. Moreover, the presence of other people was detrimental to perceived restorativeness, which brings the discussion to the impact on perceived restorativeness of factors other than the physical environment.

Even though perceived restorativeness measures aim to specifically link objective physical qualities in an environment to restorative effects, many studies identified the impact of several other factors on perceived restorativeness as well. For instance, based on a sample of 127 UK members of 'walking for health' groups, aged older than 55, Marselle et al. (2016) found that besides perceived restorativeness being significantly and positively correlated with perceived naturalness and perceived biodiversity, a further significant positive correlation was present with the perceived intensity of the walk.

The perceived restorativeness of environments also varies with social context, such as the people you are with, and place attachment (Q. Liu et al., 2020; Scopelliti & Giuliani, 2004). Furthermore, the level of restorativeness has been shown to depend on the restoration need of individuals (Hartig & Staats, 2006), as shown in the study among 103 Swedish students. For students, restoration need (high mental fatigue) was assumed higher at the end of a day at college than at the start of the day (low mental fatigue). The participating students were shown 50 slides of either urban (non-restorative) environments or nature (restorative) environments. They were asked at those different times of day to judge the likelihood of attentional recovery by indicating on a 7 point scale, ranging from very unlikely to very likely, the expected outcome of walking in the shown environment for one hour using items such as 'renew energy', 'order my thoughts again' and 'regain the ability to concentrate'. Results showed that for both the low-fatigue and the high-fatigue moments, students assessed the likelihood of recovery from attentional fatigue higher for the natural setting than the urban one. In addition though, students with a larger restoration-need attributed more restorative value to a natural setting over an urban one, than the students with the lower restoration-need.

Perceived restorativeness thus, first, seems a good indicator of actual restorative quality of an environment; second, succeeds in also distinguishing smaller differences in less contrasting environments, such as within an urban green setting; and third, may be impacted by factors beyond the physical environment, such as presence of other people, intensity of the respondent's activity, and 'need' for restoration.

2.5 Urban green at the neighborhood and street level

Most studies discussed in the previous section have either been concerned with nature environments only or used contrasting environments to find differences in stress recovery or restorative value. This tradition may be too simple a representation of reality (Pearson & Craig, 2014). It remains uncertain to what extent findings on 'wild nature' are applicable to urban nature at the neighborhood or even residential street level. This is a relevant research question as these environments may lack some of the key properties and central mechanisms of SRT/ART that are supposed to cause the effects of nature on psychological health, such as eliciting effortless fascination by natural elements, or providing a sense of being away, while the context can still be clearly urban, countering the effortless fascination or sense of being away. Moreover, in many instances, the inclusion of natural elements in urban environments will reduce 'overview' and this reduction of overview may even be the purpose of the natural elements: to take something else from view.

In this section, the empirical evidence supporting SRT/ART in relation to the restorative value of urban green at the neighborhood and residential street level is assessed. Because the number of such studies is much more limited, this section is not subdivided into the topics, used in the previous section. Available studies tend to be concerned with either large urban green spaces such as urban and neighborhood parks, and green corridors, or with neighborhood or street green. In the latter case, urban green tends to be mixed with non-green, implying researchers need to distinguish the presence of green in a particular area, which is often arbitrarily demarcated.

2.5.1 Measuring presence of urban green

Commonly used spatial measures are generic aerial view measures, such as the normalized difference vegetation index or NDVI - measure, using satellite imagery to detect differences in reflection of red and infrared lights of earth surfaces, resulting in an index indicating the level of presence of vegetation (developed by Tucker, 1979), and tree cover density, often defined as the percentage of an area covered by tree canopies. Alternatively, measures of the eye-level field of view occupied by natural elements have been applied, as well as more generic greenness concepts. Last, separate natural elements may be distinguished. Studies are discussed zooming in from neighborhood level and generic measures of presence of urban green, to street level and measures on the level of separate natural elements.

Generic aerial and satellite view measures

In a study among 529 Bulgarian university students, Dzhambov et al. (2019) found that a higher NDVI and tree cover density (based on open EU data[1]) was associated with participants having a perception of more green space, which was considered to have a higher restorative quality and to improve psychological health as measured on self-reported measures of psychological health such as the affective response of anxiety, and psychological resilience. Two further examples investigating the relationship with neighborhood green and psychological health using a similar approach are Cohen-Cline et al. (2015) and Beyer et al. (2014) who linked NDVI-measures and self-reported depression, stress, and anxiety. Findings indicated that significantly lower levels of depression, anxiety and stress were reported in neighborhoods with higher NDVIs. Some studies distinguish separate natural elements or element types from aerial views. For instance, Astell-Burt and Feng (2019) used satellite imagery to distinguish between tree canopy, grass and 'other ground cover vegetation', rather than relying on a fully generic measure of land covered by vegetation. Psychological health

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[1]https://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/status-maps/2015

measures were obtained from 46,786 adult Australians and related to the natural elements and surfaces within a 1.6 km road network distance from their home. Results indicated that the presence of more trees is associated with better psychological health and more grass cover with lower psychological health. A limitation of this and other studies based on satellite imagery is that tree canopies obscure potential ground covering vegetation. A review study (M. Van den Berg et al., 2015) covering 40 studies on health benefits of nature in the living environment, included general studies on perceived health and mortality, and 19 specific studies concerned with the relationship between psychological health and the experience of urban green. The review confirmed that green space in the living environment tends to be measured in terms of dominant land use or surface cover for standardized blocks of land (e.g., a grid 25m x 25m). However, Gascon et al. (2016) concluded that NDVI may not be as suitable for smaller areas, e.g., buffers smaller than 100 meters, because of their lower predictive value. Generic aerial view measures seem of value for cross sectional data and epidemiological studies, linking more generic characteristics of an environment to certain (psychological) health outcomes. Their use is limited, however, for addressing different types of green elements, especially on eye level, which is the level experienced by citizens.

Generic field-of-view measures

In addition to aerial and satellite view measures, researchers have used the percentage green elements in the view from the perspective of the human eye level. In Jiang et al.'s (2014) study, subjects were shown photos of suburban residential streets varying in 'tree density', measured by the percentage of pixels occupied by trees in eye-level pictures of the street. Cortisol (before and after) and skin conductance (continuous) were used to measure stress reduction among 158 young American adults with an average age of 21.2 years, and correlated with the percentage of the view occupied by trees. Findings indicated that - for men - increasing tree cover density led to increasing stress recovery until at a certain level of tree cover density stress recovery became stable, and then decreased again at an even higher level of tree cover density. For women, surprisingly, no relationship was found, making this the only study finding such an absolute difference, as discussed before. Y. Liu et al. (2020) related self-reported psychological health to the percentage of the view occupied by grass and trees in the neighborhood, using automated assessment of the percentage of the view occupied by such natural elements. Results confirmed the findings of previous studies and showed a positive association between psychological health and the percentage of the view occupied by grass and trees. Even the *color* green has been used as an indicator for the presence of urban green, and linked to various measures of restoration (Janeczko et al., 2020). Other generic measures of 'greenness' of a neighborhood are measures such as '*green impression'* (Van Dillen et al., 2012), and the more abstract measure *'naturalness'* (Marselle

et al., 2016; A.E. Van den Berg et al., 2014). Regardless of the specific measure used, on a generic level, in these studies more green was associated with improved psychological health. However, field of view measures largely remain on the level of (visible) quantity of urban green, with some distinction with respect to proportions of view per type of natural elements, but no distinction of how the different elements are placed, i.e., their configuration in the environment.

Distinguishing separate nature types and natural elements

Some studies distinguish separate natural elements, aiming to find restorative quality not only of a total setting, but also of those separate elements. For instance, Nordh et al. (2009), using a combination of affective measures, perceived restorativeness and likelihood of restoration, identified the contribution of different elements to the restorative value of small urban parks. Photos of 74 small urban parks (maximum size of 3000 m^2) were shown to 52 Swedish university students. The parks varied in paved surface areas and grass, ground vegetation, flowers, bushes, trees, and presence of water. The restorativeness of a park was related to the percentage of the photo covered by each of those elements. Results indicated that trees, grass and bushes were most important to restorativeness. Nordh et al. (2011) administered a choice task to 154 Norwegians, offering choice sets of different small park profiles varying the attributes trees, bushes, grass cover, flowers, water features and other people. Under the scenario of being fatigued and looking for a place to rest, respondents were asked to choose the profile they preferred. Using conjoint analysis, trees, grass and other people were shown to influence the choice most and no significant differences were found between socio-demographic groups. Both studies thus managed to distinguish the influence of separate natural element types on restoration, but do so for small parks rather than urban residential streets. The configuration of those elements within the setting was not part of the study.

2.5.2 Urban street settings

Urban green measures at the street level may address different kinds of streets, such as city center shopping streets, streets with primarily a traffic function, or residential streets. Studies are discussed zooming in on street level and measures on the level of separate natural elements and their configuration within the street.

The few studies that are specifically concerned with residential streets tend not to distinguish between separate natural elements. For instance, F. Weber et al. (2014) conducted qualitative research applying street interviews in Berlin and Cologne among 313 respondents. Respondents were asked about their preferences for road design along busy arterial roads and small businesses in inner city areas. From the answers, only trees were recognized as

separate elements. All other elements were broadly categorized as roadside vegetation, varying in degree of wildness and orderliness. Findings indicated that beyond trees, relatively wild roadside greenery was preferred. Alternatively, E. Weber and Schneider (2021) conducted a qualitative study on the benefits of green residential alleys for psychological health. Nine respondents joined focus group sessions, and 22 respondents were interviewed. Findings indicated that green alleys contribute to psychological health. Respondents appreciated biodiversity, variation in vegetation (color, size, texture), a cohesive design and the general impression that the green was well-kept, but separate elements were not distinguished. Similar to many other studies, these results should be judged in light of the small sample and sample selection bias because subjects were recruited from a group that actively participated in planning or developing the green alleys. Navarrete-Hernandez and Laffan (2019), using photos of actual locations in Chile, measured perceived stress of 240 visitors to an architectural event, for 4x3 different settings of a tram line, pedestrian street, avenue and small street combined with a small, medium or large green intervention. In manipulating the photos, specific natural elements were used (grass, trees and shrubs/hedges). Weather, presence of people and cars, urban background and pictorial qualities like lighting and brightness were kept constant. A significant positive effect on perceived stress was found for urban green, the effect increasing with the scale of the intervention. However, to quantify the relationship between self-reported affect and stress level associated with the site and urban green, only the categorization small, medium and large intervention was used. So, even though clearly separate natural elements were distinguishable, only the total effect on perceived stress of the green elements together was examined.

The studies discussed so far were concerned with trees and several forms of surface plants (flower, shrubs), which are grouped as horizontal green. However, urban green can also be vertical green. E.V. White and Gatersleben (2011) specifically investigated the impact of green roofs and façade (vertical) green on restoration among 188 participants in the UK. Respondents assessed the restorative value of pictures of homes with four digitally added variations of roof green and one of vertical green, using different measures. Results showed that vertical green was considered significantly more restorative and resulted in significantly more positive affective responses than façades without vertical green. Moreover, façade green and the 'meadow roof' type were considered most restorative out of the five variations. Considering the pictures used in the research, the façade green was the most realistic and, especially in the UK, most common, which may have influenced the results. Furthermore, considering that generally people will likely have a clear view of vertical green, while the

natural elements on a green roof are less visible from street level, the finding that façade green was considered more restorative than roof green, is not surprising.

Addressing the potential role of configuration of urban green elements in urban street settings, Zhao et al. (2020) reported the results of an online study based on a convenience sample of 1,473 Chinese participants recruited through students' networks, who were asked to rate the perceived restorativeness of urban streets. The urban street scenes varied in built environment context, such as presence of power lines and fences, traffic, and urban green in terms of the continuity of trees along the street, plant diversity, percentage view occupied by urban green and a few specific combinations of green elements, such as 'mixed' and 'tree or tree with grass'. The authors concluded that higher quantity and more diverse urban green was perceived as more restorative. The continuity of trees along the street was found to not be of significant influence.

To date, Lindal and Hartig (2015) is the only study explicitly focusing on the restorativeness of several green elements and their configuration in residential streets. Computer generated images of residential streets with different architectural styles and street greenery, varying the number of trees and presence of flowerbeds and grass, were shown to a sample of 188 Icelandic respondents, who were asked to rate the streets in terms of their restoration likelihood (similar to Nordh et al., 2009). Results indicated that restoration likelihood was significantly and positively correlated with the number of trees and presence of flowerbeds. No significant interaction between architectural style and type of street vegetation was found.

Overall, literature on restorative environments at the neighborhood level thus distinguishes several types and layouts (or configurations) of natural elements in residential streets, relevant for the restorative qualities of a particular (green) street design. The main relevant types are: trees (e.g., Lindal & Hartig, 2015; Nordh et al., 2009, 2011; F. Weber et al., 2014; Wolf et al., 2020); forms of horizontal green, such as grass, flowers, hedges, bushes and water (Lindal & Hartig, 2015; Nordh et al., 2009, 2011; Todorova et al., 2004); and vertical green (E.V. White & Gatersleben, 2011). Moreover, specific combinations of different natural elements were shown to be of additional value, i.e., interaction effects between different types and subtypes, may play a role (e.g., Nordh et al., 2011; Vermeulen, 2013; Young et al., 2020). Regarding the configuration of those elements within the residential street, Lindal and Hartig (2015) showed the relevance of the size and arrangement of trees in a street, distinguishing arrangements along one and along both sides of the street, and R. Weber et al. (2008) found that symmetrical vegetation (also in height and type) along the street is preferred. Based on this, the following

common configurations are identified: natural elements in (residential) streets may be absent, singular or solitary, linear on one side and linear on both sides of a street.

2.6 Methodological aspects

A second aim of the literature review is to describe the state of the art in the methodologies used in research on the restorative value of green space. It constitutes the background against which operational decisions underlying this PhD project will be made in the next chapters. In discussing methodological aspects, the successive stages, from the basic design of the study to data collection and analysis are followed, discussing possibilities and limitations of different approaches.

2.6.1 Research design and key concepts

The most fundamental decision is the choice of research design. The review of the literature shows that the majority of studies have been based on some quasi-experimental design. However, some violate principles such as not including a control group, and/or not randomly assigning treatments, and/or not including before and after measurements when aiming to measure change. These issues complicate the interpretation of the association between (urban) green and psychological health in terms of causality. Quasi-experimental designs and the use of relatively small samples also tend to limit possible analyses of the association between green space and restoration by socio-demographics, especially on a detailed level.

A next critical operational decision is the measurement of the key concepts. Currently, four main approaches have been used to measure stress and restoration and it should be noted that different variants of these four main methods have been applied. Moreover, the field has continuously combined and integrated measures (e.g., Lindal and Hartig, 2015; Stigsdotter at al., 2017). Note that for all four measures, other psychological processes (for instance, suddenly remembering an urgent errand) may influence the measurements.

First, affective scales have been used to measure the impact of nature experience on affect as a correlate of stress and stress recovery. Affective responses (e.g., 'happy' or 'at ease') are linked to a specific time and location (e.g., Browning et al., 2020; Ryan et al., 2010). This is a subjective approach and often affect is not measured during nature experience, risking possible bias due to the problem of memory recall of emotional states, or quick dissipation of short term effects.

Second, in addition to self-reports of affective responses, studies have relied on *physiological* stress reactions (e.g., Hedbom et al., 2019; Jiang et al., 2014; Park et al., 2010; Stigsdottir et al., 2017; Tyrväinen et al., 2014). Such measures are real-time and objective, with a resulting lower risk of bias recognized for affective measures. However, physiological reactions are comparable for different types of stress, and a certain change in a physiological reaction may be caused by opposite triggers (e.g, a rising heart rate may be a sign of fear or enthusiasm) (Strube et al., 2016), complicating linking specific physiological stress or stress recovery reactions to specific stressors or restorative qualities of environments. Slier (2014) confirmed inconsistencies in physiological measurement of heart rate, heart rate variability and skin conductance in relation to on-screen viewing of different environmental settings, and also found evidence of a large impact of external interferences such as noise or movements. Furthermore, a practical disadvantage is that professional equipment needs to be carried either by the researcher or respondent. An increasingly more viable tool to measure some physiological reactions is the smartphone, although the precision and reliability of smartphone measurements are less than of professional equipment. An advantage of using smartphones and other personal wearable devices, such as smart watches and fitbits, is that many people tend to take their smartphone anywhere they go and always have it turned on, allowing continuous measurement, even if in some nature areas there may be no network connection. It is a non-intrusive measurement tool and easily fits the requirements for measuring physiological reactions of the human body: the measurement device should be portable; it should function during short measurement periods; interference due to other factors (such as temperature) should be avoided and the device should be battery-powered (Tsunetsugu et al., 2010). While technological advancements have made the measurement of physiological reactions cheaper, less intrusive, less burdensome for subjects, more precise, and delivering near instant digitalized data, the interpretation of the measured values remains complicated, and it is difficult to infer to what extent the physical environment is the cause of the physiological response.

Third, the *cognitive* approach uses measurements of performance in cognitive tasks such as sustained attention, logical thinking and memory (e.g., Berman et al., 2008; K.E. Lee et al., 2015). Cognitive performance has been shown to increase after nature experience. Moreover, cognitive performance improved significantly more after experiencing a natural environment than after experiencing an urban environment, which is considered a sign of the restorative effect of nature. However, causality cannot always be established and cognitive performance may also be influenced by physiological factors, such as the stimulating effect of coffee.

Fourth, several measures of *perceived restorativeness* have been developed. According to Han (2018), who reviewed 65 studies, the Perceived Restorativeness Scale (PRS, developed by Hartig et al., 1997) is the most commonly used scale and has the best generalizability and sensitivity properties for measuring the perceived restorative quality of an environment. Moreover, PRS is not only suitable in research on strongly contrasting natural and built environments, but can also distinguish between environments that are more similar (McAllister et al., 2017; Tenngart Ivarsson & Hagerhall, 2008), which was shown to be problematic for several other measures. One of the main strengths of PRS in relation to restorative environments is that it explicitly links restoration to qualities of the environment according to the four components of ART. The scale originally included 17 statements about the four components of the restorative quality of environments: being away, coherence, fascination and compatibility (some examples of the statements are *'Spending time here gives me a good break from my day-to-day routine'* for being away, and *'There is much to explore and discover here'* for fascination). Pasini et al. (2014) showed that confirmatory factor analysis supported the discriminant validity of three of the four components 'being away', 'fascination' and 'coherence'. Additionally, they separated a new component 'scope' from 'coherence'. The component 'compatibility' was previously shown to not be a factor on which the intended items loaded convincingly. However, the four components are to some extent correlated. Being away, fascination and compatibility have been found to be easily combined into a general subscale of restorativeness (Hartig et al., 1997), while coherence seemed to be a more independent factor (M.P. White et al., 2010).

Because of the interrelation between stress recovery (SRT) and attention restoration (ART), studies often measure combinations of affect, stress and stress recovery, cognitive performance, sometimes combined with perceived restoration, and restorativeness. The interrelations between SRT and ART, and their measures, added to the notion that a more general subscale of restorativeness may exist, led some researchers to apply a measure of Restoration Likelihood (RL) (Lindal & Hartig, 2013, 2015; Nordh et al., 2009; Staats et al., 2016). Statements on an affective response and perceived restorativeness are related to the perceived likelihood of restoration of cognitive functioning. RL is a novel approach, potentially helping to move towards a comprehensive measure of the restorativeness of an environment. Such a unidimensional measure of the restorativeness of an environment and its elements seems useful. This is supported by A.M. Weber and Trojan (2018), who used the term restorative value to capture the broad spectrum of measures of restorativeness.

2.6.2 Representation of environments

An important distinction related to the representation of environments is between studies that measured the constructs in a real environment and studies that are based on simulated or virtual environments. The former capture the actual full experience of an (urban) nature environment, including many characteristics and the dynamic context that are not the object of study, such as parked cars and weather. Studying participants in a real environment may result in higher external validity, but the influence of the broad array of other factors is difficult to establish, resulting in lower internal validity. The use of a representation of environments allows controlling such other factors by leaving them out or keeping them constant (e.g., Laing et al., 2009). A study reviewing 148 research articles concluded that virtual representations (which were called simulations or simulated natural landscapes) "*are an ecologically valid test of nature exposure"* affecting both health and cognitive performance and that specifically when researching perceived restorativeness, virtual environments are found to lead to restoration (Browning et al., 2021, quote: p. 712 (26)). Representing environments is done by showing photos and videos of existing environments, or by showing computer generated graphics of existing or fictional environments, where fictional environments can also represent alternative designs for existing environments.

Photo and video representations of real environments

As for photo and video representations, Hartig et al. (1997) examined differences in perceived restorativeness between 95 university students randomly assigned to either being in an environment or viewing that same environment in a video. Applying PRS, no significant differences were found. Kjellgren and Buhrkall (2010) compared several measures related to ART and SRT (affective and physiological) at base line and before and after experiencing a real environment or viewing a screen with photos of the same environment. The 18 Swedish participants were recruited from a group under treatment at a stress clinic, intended to imply a need for restoration. Both environments were shown to foster restoration, but some significant differences were found between experiencing real environments and viewing them, leading to the conclusion that although both environments facilitate restoration, real environments do so slightly better. Findings of both studies are thus in line with the review of Stevenson et al.'s (2018) (in which the two studies were not included), which indicated that exposure to real environments still seems more effective in attention restoration than exposure to representations of environments. Further support is found in research showing video representations of nature scenes being able to help relax and improve mood of people in isolated and confined environments, like space stations or arctic research stations (Anderson et al., 2017).

Furthermore, photo and video representations of actual environments may be supplemented with additional virtual elements. An example is Hurtubia et al. (2015), who used representations in stated preference surveys when researching public space, altering photos of places with a variety of additional attributes, such as façade color, street trees, people, infrastructure layout and cars. This approach assures that the context of the systematically varied attributes under research remains constant. They conclude such images are feasible for stated preference tasks as long as there is caution in preventing bias due to omitting certain elements not under research, although it can be argued that omitting some elements is not fundamentally different than adding others; moreover, added virtual elements will always obscure what was visible 'behind' them. Photo and video representations of real environments have thus been shown to possess restorative value, and such representations of environments lead to comparable, but not to equal, restorative effects over the corresponding real environments.

Virtual environments representing existing or fictional environments

Virtual environments, as opposed to photo or video, could either represent an existing environment, or a fictional one. Virtual environments are used on a regular basis in restorative environments research. Creating virtual versions of actual environments is attractive for the level of control in an experimental setting. Dynamic urban context, such as traffic, weather and street litter, can easily and uniformly be included or excluded. Furthermore, the specific aspects under research can be easily systematically manipulated.

An example of using a virtual version of an *actual* environment is Laing et al. (2009), who approached a random distributed sample of the total population of Aberdeen (UK) with a paper questionnaire on virtual environments. Respondents (n = approximately 600; exact number not provided) were asked to indicate how valid they considered the visualization in relation to choices in visiting the sites and providing a sense of safety and attractiveness. Findings indicated that the virtual environments were considered realistic to very realistic by nearly 80% of the respondents. Based on ordered logit modeling, the results showed that varying the environment (such as trees or paths) as well as weather, season and presence of other people significantly influenced whether respondents would visit the environment, and how safe and attractive they would perceive the environment to be. This implies that respondents felt the virtual environment sufficiently convincing to base their assessment and potential choices on. The results led the researchers to conclude that the use of virtual environments and visualizations is "*…appropriate … within environmental economic surveys"* (Laing et al., 2009, p. 355), which is a reguler approach in urban planning and design. Moreover, virtual *fictional* environments have also successfully been used to investigate aspects of restorativeness

(Lindal & Hartig, 2013, 2015). As the quality of virtual fictional environments can technically be identical to that of virtual existing environments, their potential effects should be assumed to be the same as those of virtual existing environments.

Level of realism of representation and 'presence'

When using computer generated graphics, the representation can range from very realistic to abstract. The current state of technology allows very detailed and realistic virtual environments, which may even be viewed in interactive 3D, increasing the feeling of presence. As to the degree of realism, Sanchez-Vives and Slater (2005) argued that less emphasis should be placed on striving for realism, arguing that computer graphics with a slightly less perfect representation of reality achieve similar results as the brain will fill in the missing information. In general, however, it is believed that for environmental research and concrete urban designs, the more realistic the representation, the stronger the effects.

Related to the degree of realism is the concept of 'presence', the feeling of actually being in a location. The very fast and continuing development of computer power allows creating high quality virtual environments, including realistic lighting, shadow and texture, offering high potential for increased presence. Litleskare et al. (2020) argued that 'presence' is key to the strength with which psychological effects are attained. The sense of presence is influenced by screen size (De Kort et al., 2006; Hou et al., 2012), which may find its optimum in using head mounted displays for coverage of the full field of vision and full virtual reality experience (Rockstroh et al., 2020). Other relevant factors are the level of *"disposition to become involved in mediated environments"* (Hou et al., 2012; p618) and context. A virtual environment with context can lead to more presence than a real one without (Villani et al., 2012). An interesting example is the use of a beach lounge chair for respondents to sit in when being immersed in a virtual beach scene (Anderson et al., 2017).

2.6.3 Sampling

An examination of the literature signals two serious sampling issues. First, a large share of the studies rely on a convenience sample. Many studies involve university students and young-aged subjects. In their review paper of 32 studies, McMahan and Estes (2015) report that the average age of the subjects varied between 20 and 28.5. Similarly, Shuda et al. (2020), reviewing 12 studies, indicate that half of these studies involved university students and similar age groups. Bowler et al. (2010), Han (2018), Ohly et al. (2016) and Stevenson et al. (2018) reported the same tendency. Other studies focused on the middle-aged and elderly (Yu et al., 2020), but relatively few studies included the general population.

Second, many studies relied on relatively small samples. A third of all studies included in the six discussed review studies (Bowler et al., 2010; Han, 2018; McMahan & Estes, 2015; Ohly et al., 2016, Shuda et al., 2020; Stevenson et al., 2018), had 50 or less respondents, and more than half had 100 or less. This can be explained by the use of quasi-experimental designs and relatively labor-intensive measurement techniques, such as physiological measurements. On the other hand, larger samples have been the rule in other fields of study. In any case, small sample size affects the significance of the results and more importantly the opportunities for more detailed analyses.

2.7 Conclusions

In this chapter, the theories that triggered this thesis have been introduced, relevant empirical research has been critically assessed and methodological approaches have been discussed and criticized. The topic of the restorative value of urban green space has been studied in the context of stress recovery and attention restoration theory. Although SRT covers a wider set of psychological processes and attention restoration is more specific, these theories offer the motivation and context for the present PhD project. Both theories argue the benefits of natural environments in stress recovery and attention restoration and, thereby, for psychological health. Natural environments are assumed to have beneficial effects on affect, afford stress recovery, both physiological and perceived, improve cognitive performance and are perceived to provide more restorativeness than urban environments.

The empirical evidence supporting these theories is mixed and a broad spectrum of different measurement scales and tools complicate comparing findings. Moreover, the methodological foundation of many studies cannot escape criticism. First, the majority of studies is based on quasi-experimental designs using relatively small samples. The small sample size leaves little room for disaggregate analyses and involves low confidence levels. Second, a large proportion of the empirical studies have relied on convenience samples, mostly consisting of students and co-workers. By definition, convenience samples have low generalizability and the use of psychology students may even strongly bias the results. Third, the face validity of many studies may be questioned. The use of scary movies and similar instruments may trigger anxiety, but the underlying process is different to triggers of chronic environmental stress, and therefore these triggers are not necesssarily relevant to the study of environmental stress in current day urban environments. Fourth, the causality of the examined relationships has often been difficult to prove, which is an issue of concern. Fifth, studies relying on physiological measures of stress are problematic in that fundamentally different, even antagonistic, triggers

may cause the same physiological response. Finally, studies use either real nature experience or have participants view representations of nature, such as photos, videos or computer generated images of virtual environments. Although actual nature experience shows stronger restorative effects, the use of virtual environments is considered a valid means of measuring restorative effects of environments.

If these methodological issues are ignored and the mixed findings are considered, on balance empirical studies tend to support the restorative effects of nature, especially in real settings although similar but smaller effects have also been found for virtual nature experience. The review of the literature has also indicated that relatively few studies have been concerned with urban green, and particularly with the impact of residential street greenery, separate green elements and the way they are configured within the street. A gap in knowledge, thus, exists in regards to the restorative value of urban green elements at the residential street level. At such a detailed scale, the restorative effects may be expected to be small and possibly difficult to discern. As the separate influence of elements and their configuration is also interconnected with the rest of the environment, identifying them individually is rarely attempted. This study sets out to examine this topic.

Chapter 3

Research design

3.1 Introduction

Empirical backing of the benefits of nature experience for psychological health through restoration has led to the idea that natural environments can be considered restorative environments. However, research on restorative environments has mostly compared strongly contrasting natural and urban environments. Only a few studies used subcategories within nature in urban environments. Moreover, it remains uncertain to what extent the two dominant theories in restorative environments research are applicable to urban nature in general and small scale natural elements at the level of residential streets in particular. To date, research on the restorative value of urban green elements in residential streets is relatively scarce.

To address this gap in scientific knowledge, this chapter first argues the relevance and potential of urban green at the residential street level in relation to restorative value. The urban greenscape is defined as the specific object of study. Second, objectives and research questions are formulated and a conceptual framework is presented linking objective attributes of urban green, to restorative value. In particular, measurement of the restorative value of an environment is addressed. Choices in representing environments, experimental design and sampling are discussed.

3.2 Small scale green in residential streets: the urban greenscape

Restoration due to nature experience has been reported not only for large scale natural entities, such as national parks, in which one generally is fully immersed in nature, but also for urban nature, such as urban parks. Research claims that large urban green areas diminish fatigue and offer restoration equal to grand nature (e.g., Tyrväinen et al., 2014; Wilkie & Clements, 2017). Urban research on nature in cities has generally focused on such large green entities that are intentionally visited for leisure and recreational activities. However, people spend much more time on activities other than visiting nature or urban green space. Some authors even argued that city dwellers experiencing nature has actually become a rarity (e.g., Cox, Hudson et al., 2017). This is, among others, due to distance to available urban

green as distance also determines accessibility and thereby frequency of visiting. Natural elements in close vicinity of the home are more likely to be part of the individual's activity pattern, providing frequent restorative experiences without requiring extra effort. Additionally, streetside greenery is readily available for purposes of immediate release and destressing, functioning as an escape space (Miller et al., 2014).

Research (Hong et al., 2019) showed that lack of availability and accessibility (nearby) is the main constraint for people to visit urban green space, leading to less 'use' of urban green. Providing nearby nature is thus important in order to get restorative effects more regularly and bringing nature to neighborhoods and residential streets can make the experience of nature more common again. The fact that street greenery may also be viewed through a window, which research shows has significant effects on cognitive (e.g., K.E. Lee et al., 2015) and affective measures (e.g., Soga et al., 2021), further increases the restorative potential of natural elements on street level.

However, to what extent such small green spaces or even separate natural elements in cities offer similar restorative benefits is under-researched. Consequently, little is known about the restorative value of small-scale elements in cities, such as street trees, front yards, wall climbing plants and green strips. The question then is whether the claimed restorative effects of nature can also be shown for urban green at the street level. As large scale urban green space and small scale natural elements in neighborhoods and residential streets may affect psychological health differently (Van Dillen et al., 2012), it is necessary to first distinguish between different scales and forms of nature in cities and what motivates their use.

In this research project, nature and natural elements in cities are called Urban Green. Large entities of nature in cities, such as parks, are referred to as Urban Green Space. Small-scale elements and single elements in the living environment, such as a tree or a row of hedges are referred to as Urban Greenscape. This distinction acknowledges that nature in cities is not always a *space* that is *actively* sought, but can also be a single element 'accidentally' encountered when going somewhere. The main differences between restoration due to nature experience in urban green space and greenscape concern purpose (recreation vs. passing through), choice (conscious choice vs. unconscious encounter), duration (relatively long vs. short) and frequency (low vs. high). It is hypothesized that separate natural elements in the urban greenscape have a positive psychological effect that will be accrued more frequently. If one is 'continuously' in an urban environment with natural elements, one would potentially 'continuously' experience the positive psychological effects of restoration, next to negative

psychological effects of urban environmental stressors. The question then is how and to what extent the urban greenscape provides restorative value similar to other forms of nature.

The small scale natural elements potentially offer important advantages in providing restorative value to citizens: they easily fit in the limited available space and are frequently and often unconsciously encountered on the way to and from home. Honold et al. (2016) showed that a higher frequency of viewing small scale natural elements corresponded with lower physiological stress levels, suggesting that increasing the frequency of multiple small nature experiences in cities is a promising approach. Moreover, repeated exposure to natural environments provides similar restorative benefits each time (Jones et al., 2021), suggesting a potential for accumulation. Accessibility (Doick et al., 2013) and distance (Ponje & Timmermans, 2005), both very relevant for parks (Zhang et al., 2017; Tu et al., 2020), are largely irrelevant for small-scale natural elements in urban streets.

On the other hand, there are reasons why the restorative value of the urban greenscape may be expected to be smaller than the restorative value of urban green space. First, the nature encountered is smaller in size. While experiencing the urban greenscape, citizens will be in an urban environment, including its background, noise, smell and traffic, which have been argued to be major stressors. Second, the encounter is shorter in duration, while the psycho-physiological process of recovering from stress is known to be relatively slow (Cacioppo et al., 2016). On the other hand, K.E. Lee et al. (2015) found that during a mentally demanding task even a 40 second break looking at a green roof already had a significant positive effect on task performance. Third, because the urban greenscape may not be perceived as 'nature' (Church, 2015), it potentially also lacks nature's full restorative value. Finally, because the encounter is often not actively sought, compatibility to restoration is less important and unconscious effects may not be measurable (Beute and De Kort, 2013), as opposed to a conscious park visit which has been shown to result in measureable psychological effects (e.g., Tyrväinen et al., 2014).

Despite the restorative value of the urban greenscape presumably being smaller, and thereby potentially challenging to show, the higher frequency and lower threshold in experiencing it may result in a significant positive influence on psychological health of city dwellers. This makes it an important research direction.

3.3 Research questions and conceptual framework

The project aims to reduce the scientific gap on the restorative value of the urban greenscape and its constituent elements and configurations, by addressing the main research question: *What is the nature and strength of the relationship between different green elements and configurations of the urban greenscape and restorative value?* This question is divided into a set of sub-questions: (1) How to best measure the restorative value of an environment and its constituent elements and configurations?; (2) Are the presumably relatively small restorative values of elements and configurations in the urban greenscape discernible?; (3) Does taking separate elements and configurations into account lead to better predictions of restorative value than researching the urban greenscape as a whole?; (4) Can Stress Recovery Theory (SRT) and Attention Restoration Theory (ART) be extended to the urban greenscape?

The current research project aims to answer these questions and assess the restorative value of elements and configurations of the urban greenscape in the living environment. This can help in formulating general guidelines to better equip urban planning and design professionals to optimize the design of the urban greenscape as a restorative environment. With improved design, residential streets may increasingly serve as restorative environments, contributing to psychological health and well-being, making cities better places to live.

The conceptual framework, underlying this project, links objective attributes of natural elements in the urban living environment to psychological restoration through the environment's restorative value, leading to psychological health, which is considered a prime contributor to well-being. Environments are experienced as stressing or restorative, depending on their environmental qualities and type and intensity of stimuli load. Urban environments tend to be rich in rapidly changing stimuli (such as fast moving people and vehicles, and noise), increasing the chance of being experienced as stressing. By contrast, natural environments tend to generate lower intensity stimuli (such as softer sounds, and more subtle moving elements, and besides occasional more sudden and extreme natural sounds and movements, such as during a storm) and according to ART, provide a sense of being away, are coherent and compatible to restoration, and fascinate effortlessly, all increasing the chance of the environment being experienced as restorative. The experience of the urban living environment thus determines the restorative value attributed to that environment. Within the urban living environment, the urban greenscape and its broader urban context are distinguished.
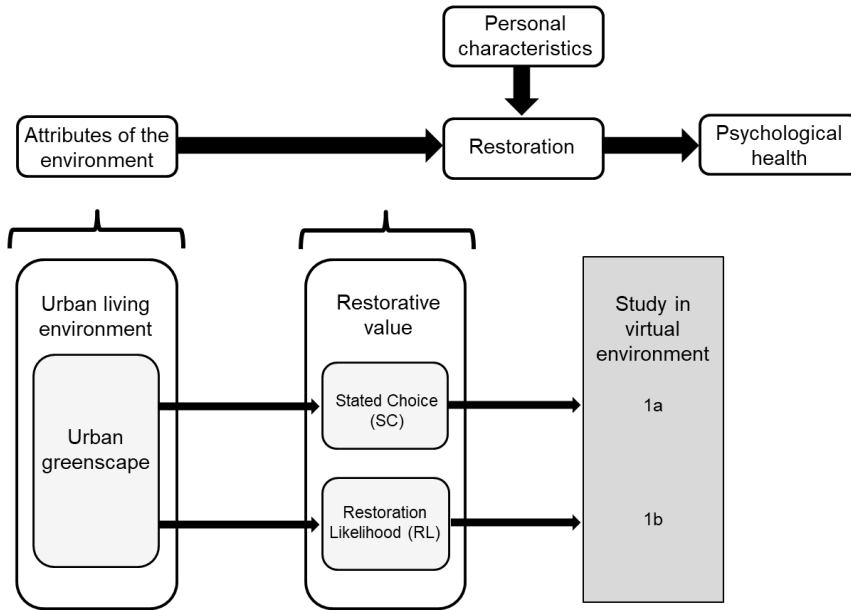
Figure 3.1 Conceptual framework of research design

The restorative value of the environment and more specifically of the urban greenscape is considered a quality of the physical environment. Despite the focus on the restorative quality of an environment, different individuals may derive varying restoration from the same environment (e.g. Houlden et al., 2017; Jiang et al., 2014, 2016; Nordh et al., 2011; Shuda et al., 2020; Twedt et al., 2019; A.E. Van den Berg et al., 2014; X. Wang et al., 2016). Personal characteristics, therefore, are included in the conceptual framework as determinants linking restorative value of an environment to actual restoration.

Figure 3.1 shows the conceptual framework including the research design. In order to establish the relationship between the urban greenscape and restorative value, the principles behind the project's research design need to be established, including distinguishing the constituting elements of the urban greenscape, as well as ways to measure the key concept of restorative value.

3.4 Research instruments

Apart from a few studies based on experimental designs, quasi-experimental designs administered to relatively small samples have been commonly used in restorative environments research. Moreover, not all studies apply randomization, control groups, and/or

before-after measurements, jeopardizing causal interpretation. In contrast, this research is based on a large survey that uses statistical models to estimate the association between certain elements and configurations of the urban greenscape and the restorative value of that urban greenscape design. The survey includes an experimental design that controls the systematic variation of attribute levels.

In the study, participants will experience a representation of an environment varying in greenscape design, but with a uniform urban context. The study can thereby focus specifically on the manipulated urban greenscape design, while keeping constant all other aspects of the environment. This increases the prospects that the potentially small differences in restorative value can be identified. Moreover, it increases the prospects that the differences are caused by the urban greenscape design manipulations, thereby finding the strength and relationship between the urban greenscape elements and configurations and their restorative values. In order to investigate the relationships between the key concepts, restorative value and the objective attributes of the urban living environment need to be defined and appropriate methods, environments and samples need to be chosen.

First, a unidimensional measure for a restorative value of an element, a configuration of elements, and urban designs is proposed. The measure indicates the strength of the restorativeness of an environment. Researchers have taken tentative steps to develop such a unidimensional measure, culminating in the development of the concept of restoration likelihood (RL), asking respondents to rate the likelihood of experiencing restoration from a particular environment. Multiple regression analysis is used to estimate the contribution of the elements of the environment to the stated restoration likelihood. However, especially in real environments, the researcher cannot control the correlation between the explanatory variables and therefore, the assumptions underlying the regression model tend to be violated, which leads to biased estimates. In the case of high multicollinearity, this approach may even lead to wrongly estimated signs and therefore to the wrong inference of the effect of nature on restoration.

In this research project, as an alternative, a choice experiment is used to develop a unidimensional measure of restorative value. This method derives a measure of restorative value from the choices respondents make in sets of choice options asking them to choose the alternative that has the highest restorative value for them. Principles are the same as those applied in using experimental designs to elicit preferences, but the experimental task differs. Such choice experiments are less commonly applied in restorative environments research.

Additionally, the regression approach to measuring and analyzing restoration likelihood (RL) is applied in this research project. Of primary concern in measuring RL is the item on likelihood of restoration, stating *"I would be able to rest and recover my ability to focus in this environment"*, and to what extent respondents agree with the statement, rated on a Likert scale. Previous research applying RL also included additional items related to the concepts '*liking'* (1 item) and '*perceived restorativeness'* (2 items), allowing the establishment of the extent to which these different items relate to the likelihood of restoration.

Several researchers have successfully applied RL (e.g., Lindal & Hartig, 2013; Nordh et al., 2009; Staats et al., 2016), asking respondents to rate environments on the four items, with slight differences in wording, depending on the aim of the study. Lindal and Hartig (2013, 2015) showed that the likelihood of restoration has a positive and strong relationship with 'liking' (preference), which in turn is strongly related with restorativeness. Staats et al. (2016) successfully replicated previous findings, indicating external validity of the scale. Figure 3.1 shows the design of the research project, relating the urban greenscape to two measurements for restorative value.

3.5 Stated choice experiment

In this research project, a stated choice experiment was designed and administered to measure the restorative value of urban green environments. Stated choice experiments have found ample application in domains such as marketing, transportation, decision science, biostatistics and econometrics for measuring consumer preferences (Louviere et al., 2000). However, the approach may also be considered a good option for measuring environmental valuations (Hanley et al., 2001). The approach involves combining the attribute levels of a set of selected attributes into multi-attribute profiles, which are placed into choice sets according the principles underlying the design of experiments. The chosen design should allow estimation of the model of interest. In most economic and societal research, respondents are invited to choose the alternative they prefer from a given choice set. Consequently, the approach allows the estimation of the assumed underlying utility function and choice model (Hensher et al., 2015). However, framing the choice task differently, other decision concepts, such as willingness to pay, can be estimated.

The key principle of this approach is to design an experiment that satisfies the necessary and sufficient conditions to estimate the model of interest, while achieving the maximum reliability of the measurements. The approach requires operational decisions with respect to the following sequence of steps: (i) selection of attributes and attributes levels; (ii) combining these

into attribute profiles and placing the attribute profiles into sets; (iii) representing profiles; (iv) framing of the experimental task; (v) defining the restorative value, and (vi) administration of the resulting design. These steps are discussed in this chapter. Further operationalization is discussed in chapter 4.

3.5.1 Attributes and attribute levels

The reliability of the responses to the experimental tasks is a function of the number of attributes and attribute levels and the number of tasks to be completed. To ensure reliability, the following operational decisions were taken. First, based on the literature review, the following elements were considered to be of relevance: grass, ground vegetation, flowers, bushes, trees, and presence of water. The configurations singular, linear on one side and linear on both sides were considered of relevance regarding the configuration. Second, in order to limit the number of attributes, the urban greenscape elements were grouped into three attributes: trees, horizontal green and vertical green, meaning different attribute levels of the same attribute in the same street profile are not possible, e.g., grass and flowers will in this research not both be present in the street. Third, the number of attribute levels was kept to a realistic minimum. Because they are not very common in Dutch residential streets, bushes and water as possible attribute levels for horizontal green were left out, despite both featuring in several studies discussed in the literature review. Furthermore, Lindal and Hartig (2015) found that size is relevant for the effects of especially trees. Therefore, for trees, the subtypes small and large trees were identified. Front yards were not included in the virtual environment streetscape design, because their very large variety complicates estimating the contribution to restorative value.

Included elements are thus: trees (subtypes small and large), horizontal green (subtypes grass, flowers, hedges) and vertical green. Each attribute can have the value 'absent', or one of the subtypes, and each subtype was chosen to be in one of the three configurations solitary, linear on one side and linear on both sides of a street. A full overview of the greenscape attributes and their levels is presented in Table 3.1. Based on these elements and configurations, a total of 280 different greenscape designs (or profiles) can be generated.

3.5.2 Experimental design: profiles and choice sets

The creation of attribute profiles and choice sets requires the choice of an experimental design. If all combinations of attribute profiles are created, de facto a full factorial design is used.

Table 3.1 The selected elements, subtypes and configurations constituting the three greenscape attributes and their levels

Elements (attributes)		Configuration (c = concentric or single, l1 = linear one side, l2 = linear both)		
		Levels	Description	
Trees	Absent	T0	No trees	
	Small Ts	Tsc	Single small tree	
		Tsl1	Row of small trees on one side of the street	
		Tsl2	Rows of small trees on both sides of the street	
	Large Tl	Tlc	Single large tree	
		Tll1	Row of large trees on one side of the street	
		Tll2	Rows of large trees on both sides of the street	
Horizontal green	Absent	H0	No horizontal green	
	Grass G	Gc	One patch of grass	
		Gl1	Grass strips along one side of the street	
		Gl2	Grass strips along both sides of the street	
	Flowers F	Fc	One patch of flowers	
		Fl1	Flowers along one side of the street	
		Fl2	Flowers along both sides of the street	
	Hedges H	Hc	One patch of hedges	
		Hl1	Hedges along one side of the street	
		Hl2	Hedges along both sides of the street	
Vertical Green	Absent	V0	No vertical green	
	Vertical green V	Vc	Wall climbing plants on a single house	
		Vl1	Wall climbing plants on several houses on one side of the street	
		Vl2	Wall climbing plants on several houses on both sides of the street	

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More commonly, however, an orthogonal or D-optimal fractional factorial design is used. In that case, a subset of attribute profiles is used that satisfies particular design criteria. Orthogonal designs satisfy the criteria of attribute level balance and the attribute levels not being correlated. If a logistic choice model is used, this property gets lost due to the nonlinear transformation that is implied. Therefore, more recently, D-optimal designs that minimize prediction error and tend to require smaller samples have become more popular.

The choice of fraction depends on the model specification. If only the main effects need to be estimated, the smallest non-saturated fraction suffices. If (selected) one-way interactions are of interest and/or unobserved interaction effects are desired to be independent of the estimated main effects, the number of required profiles increases. Higher order interaction effects are typically considered negligible and hence ignored. Choice sets can be created such that attributes are independent within and between choice alternatives. In case of a generic function, often some randomization procedure is applied.

In the current study, the interest was in to assess the strength and significance of all one-way and two-way interactions. Consequently, a full factorial design was used. The experimental design thus consists of the three attributes of respectively seven (for trees), ten (for horizontal green) and four levels (for vertical green) generating 7*10*4=280 different multi-attribute profiles. Note that attributes are a combination of type of element and type of configuration. For each respondent, greenscape designs, or profiles, were randomly selected from the 280 possible designs. These profiles were used for both SC and RL.

As a rating task puts a relatively high burden on respondents, the number of profiles to be rated was limited to eight. The following procedure was used. Choice sets of two profiles were created by taking one of the eight profiles as the pivot and pairing this profile with the other seven selected profiles. Random selection of profiles prevents order effects, but potentially creates imbalance as some profiles are offered more often than others. With increasing sample size, the numbers of times profiles are offered increases and thereby, through the randomization, the relative differences decrease. As each variable value can be present in multiple profiles, the potential issue of unbalance becomes negligible with increasing sample size.

3.5.3 Representing profiles

First, it should be noted that experiencing real environments is not necessarily the same as experiencing representations of environments. If the aim of a study is to explore the relationship between man and his environment, exposing subjects to a real environment may

bring insight into factors that otherwise may have been neglected, such as, for instance, the influence of other people in the environment. On the other hand, the richness of information and the constant changing content may interfere with the specific research aims and introduce bias. Finding appropriate real environments that fit the requirements of the study, while simultaneously carrying a minimum of distracting information, can be a challenge. Keeping non-researched aspects in real environments as constant as possible across several locations is virtually impossible, while representations of environments have the advantage that they allow such control. In the literature, the representation of environments varies from verbal representation, to photos (or photo collages), video and 3D virtual reality (e.g., Nordh et al., 2011; Yu et al., 2020). Each of these possible representations has potential advantages and disadvantages and the degree of control depends on the means of representation.

Deciding on the specific representation involves operational decisions with respect to the two dimensions of existing vs fictional environments and use of photo/video vs computer generated graphics (i.e., a virtual environment (VE)). Regarding the first dimension, existing locations may be familiar to some respondents, and unfamiliar to others. Besides such a familiarity bias, emotional and functional values as well as memories associated with an existing place may take the focus away from the environment and task at hand, leading to less reliable responses. Fictional places do not suffer as strongly from these drawbacks, but they may still remind a respondent of a real place. Moreover, the use of fictional environments has the advantage of controlling the degree of variation in the environment and the representation may include elements and areas that have not yet been built, or that are technically not possible yet, although this specific aspect is not applicable to the current study. Lastly, for fictional environments, people are more likely to base their responses on the controlled and systematically varied aspects under study only. Other influences, such as emotional and functional values attached to an environment, are far less logical.

Regarding the choice of photo/video or virtual environments, an important consideration is that the experience of nature should be as pure as possible and not be disturbed by other factors. This is relatively difficult to achieve when using photo/video of real urban streets. Photos can only to some extent be 'cleaned' of 'other' physical elements, like people, garbage and animals. Moreover, photos of actual locations also involve the risk of not being able to control for other potentially relevant aspects, such as weather and natural lighting. This is important as weather aspects influence the general perception of an environment (Laing et al., 2009) and natural lighting was found to be similar and partly overlapping in effect with the positive psychological effects of nature (Beute & De Kort, 2014). When using video, the question arises of how background, weather and lighting can be kept neutral. Moreover, minimizing or

removing 'other elements', becomes an increasingly more complex task. Furthermore, using photos and video inherently addresses existing environments and thus involve their previously discussed issues.

By contrast, using virtual representations of actual or fictional urban green allows one to relatively easily manipulate the representation by adding or removing elements, while keeping all else constant. For example, weather and natural lighting can remain unchanged in a virtual environment. Moreover, current technology allows for very high quality graphics where, if wanted, one can even freely and interactively 'move around' in, enhancing 'presence'. Furthermore, using a virtual *fictional* environment strongly diminishes the risk of familiarity, memories and emotions, as the environment does not exist in reality. Therefore it seems logical that using computer generated visual representations of a fictional environment should lead to measurements which allow more specifically linking restorative effects to the design of the urban greenscape if the natural elements are the only things that change.

In light of these considerations, it was decided to use a virtual fictional environment in the study, because attributes levels of greenscapes can be systematically varied, while keeping everything else constant. It is assumed that this property of virtual environments leads to more valid responses. Using Lovett and colleagues' evaluation of visualization options and application criteria (Lovett et al., 2015), the use of rendered still images (static pictures) or animations (linear video) seems appropriate for the purpose, audience, available resources and limited need for interaction in the study.

3.5.4 Framing the experimental task

Once the experimental design has been created, the task that respondents are invited to complete has to be formulated. Note that the profiles and choice sets are nothing but descriptions that satisfy statistical conditions. The meaning is derived from the framing of the task, which depends on the underlying theory. As the aim of the analysis is to estimate the contribution of greenscape attributes to restorative value, respondents were invited to indicate for each choice set which street and thus greenscape design they would choose to walk through back home after a busy day. The task aimed at an implied need for restoration and thereby an assessment of the restorative value of the profiles. An additional task was formulated based on the concept of restoration likelihood, in which respondents were asked to rate each of the eight selected profiles on four statements for the same setting of having had a long and busy day.

3.5.5 Defining the restorative value

The responses to the experiment are used to estimate the restorative value of the manipulated profiles and the contribution to the restorative value of each of the attributes. Let X_{ikl} denote level *l* of attribute *k* of environment *i*. It is assumed that the restorative value of environment *i*, R_i , is a function of these attribute levels: $R_i = f(X_{ikl})$. If the restorative value is assumed to be the result of a compensatory cognitive process in which a low value of one attribute can be compensated by high values of one or more other attributes, *f* is a linear additive function: $R_i = \sum_{k=1}^{K} \beta_{kl} X_{ikl}$, where β_{kl} is the weight parameter for level *l* of attribute k.

The restorative value is assumed stochastic. Thus, $R_i = \tilde{R}_i + \epsilon_i$. Assuming that individuals will choose the alternative with the highest restorative value, the probability that alternative *i* will be chosen over alternative *j* equals

$$\text{Prob}\ (\ \tilde{R}_i + \epsilon_i > \tilde{R}_j + \epsilon_j)\ =\ \text{Prob}\ (\ \epsilon_i - \epsilon_j > \tilde{R}_j - \tilde{R}_i\ ),\ \forall\ i \neq j$$

The probability that *i* is chosen then depends on the assumptions about the error terms. If the error terms are independently and identically Gumbel distributed, the probability environment *i* is chosen equals:

$$\text{Prob (alt } i \text{ is chosen)} = \frac{e^{\tilde{R}_i}}{\sum_{i`=1}^{I} e^{\tilde{R}_{i`}}}\ ,\ i = 1,\ ...,\ I$$

The choices made in the choice experiment then allow estimating the weight parameters β_{kl} for each attribute level and the restorative value $\tilde{R}_i$. Note that mathematically, this conceptualization is identical to the estimation of utility and preference functions under random utility theory (Henscher et al., 2015).

3.5.6 Administration of the experiment

Administering a survey can be done in person or online. Using an online survey allows respondents to participate from their known and comfortable environment, and thus not causing additional excitement due to visiting a laboratory or actual environment and meeting other people. Moreover, surveying over the internet saves travel time and is less intruding as it can be done when it suits the respondent. Online surveys make a large number of respondents at relatively low cost feasible. There are, however, also some issues with using online surveys. First, an online survey on environmental topics will not contain any actual experience of the environment. Moreover, the representation of the environment may look

different depending on screen quality and size. Second, anything unclear in the survey cannot immediately be remedied or further explained. Third, not everyone is equally open to online surveys, potentially leading to sample bias with respect to certain population groups.

The setup of the study aims to find a balance between these advantages and drawbacks by using high quality virtual environments closely resembling real environments. Extensive testing prior to sending the survey invitation aimed at diminishing the risk of lack of clarity in the survey. Furthermore, the researcher's contact details were provided in case of any malfunction or unclarity, offering respondents the possibility to receive further explanation when desired.

3.6 Study area and sample

The study area is comprised of the cities of Eindhoven, Breda, Tilburg and 's Hertogenbosch in the Netherlands. These cities are the largest cities in the Province of Noord-Brabant, the Netherlands. All have a population between 140,000 and 225,000 inhabitants at the time of the survey (Statistics Netherlands, 2015). The local governments of these cities operate citizen panels that consist of adult citizens who volunteer to give feedback to their local government on actual or proposed policy. The citizen panels were contacted to invite respondents. Sampling the general population rather than convenience sampling of one or a few socio-demographic subgroups aimed to avoid the sampling limitations often found in restorative environments research.

The downside to working with the municipal citizen panels is that the panels themselves show an overrepresentation of males, ethnic Dutch people, and citizens with a high education level, and an underrepresentation of citizens with a migration background. Thus, unfortunately, the panel is not a full random sample. In total, the four panels consisted of slightly more than 15,000 potential respondents. The response rate of the panels is generally high, which, combined with the substantial number of potential respondents, is an advantage.

3.7 Conclusions

This chapter argued the relevance of small-scale urban green elements in residential streets, together forming the urban greenscape, as they allow high frequency, easy access nature experience, while not needing a conscious choice to visit these greenspaces. However, restorative effects of the urban greenscape are presumably relatively small, and potentially

difficult to establish. The conceptual framework links objective green attributes of the urban living environment to restoration through the restorative value of the environment. The main research question focuses on the nature and strength of the relationship between different green elements respectively configurations of the urban greenscape and restorative value, defined as the strength of the restorativeness of an environment.

To address some common methodological issues in restorative environments research, this PhD research project applies a virtual environment and aims to recruit a large group of respondents. The chapter outlined general decisions related to the design of the research project, with an emphasis on the choice experiment. The experiment includes the attributes trees, horizontal green and vertical green, with sublevels (e.g, grass, flowers and hedges for horizontal green). Using these attributes and attribute levels, a full factorial design is made of 280 greenscape profiles, which are visualized in a fictional virtual environment. Choicesets of two profiles form the basis for the choice experiment where respondents to the online survey are requested to choose the profile with the highest restorative value. The operationalization and findings of the study in the virtual environment are discussed in the following chapters.

Chapter 4

Operationalization

4.1 Introduction

In the previous chapter, the general research design of the PhD project was outlined. The aim of the study is to assess the contribution of green elements and configurations at the street level to the restorative value of the urban living environment. The study employs a controlled fictional virtual environment in which the urban context of the greenscape is kept constant. The study examines the restorative value of the urban greenscape using choice experiments. In addition, measures of restoration likelihood (RL) are applied. Data are collected using an online questionnaire. This chapter describes the details of the study setup. First, the design and creation of the virtual environment is discussed. Second, the questionnaire is outlined. The last part of the chapter covers the administration of the questionnaire and addresses the response, data preparation and the distribution of sample socio-demographic characteristics.

4.2 The virtual environment

The measurement of restorative value was based on experimental design data. In order to minimize possible influences of familiarity, emotional and functional values, and memories of locations, a virtual 3D model of a fictional residential street was developed by the Reality Center of Groningen University (RUG), using 3DSMAX (Autodesk Inc., 2013), Photoshop (AdobeSystems, 2013) and own software based on OpenSceneGraph (Osfield, 2002). The street was meant to look very ordinary in the sense that it may be found in any Dutch town. It was based on Dutch norms regarding layout, street width and size (CROW, 2012) and commonly used paving and brickwork. As the design of green elements in front yards can differ greatly, the houses were put directly fronting the sidewalk to eliminate any extra variation in natural elements in the street. Additionally, it makes vertical green on the facades more clearly visible. Besides streetlights, all other elements in the street (such as cars) were left out and weather aspects were kept constant across street profiles to prevent these factors influencing the results. Figure 4.1 shows a cross section of the virtual street, and Figure 4.2 shows the developed virtual environment without any green elements.
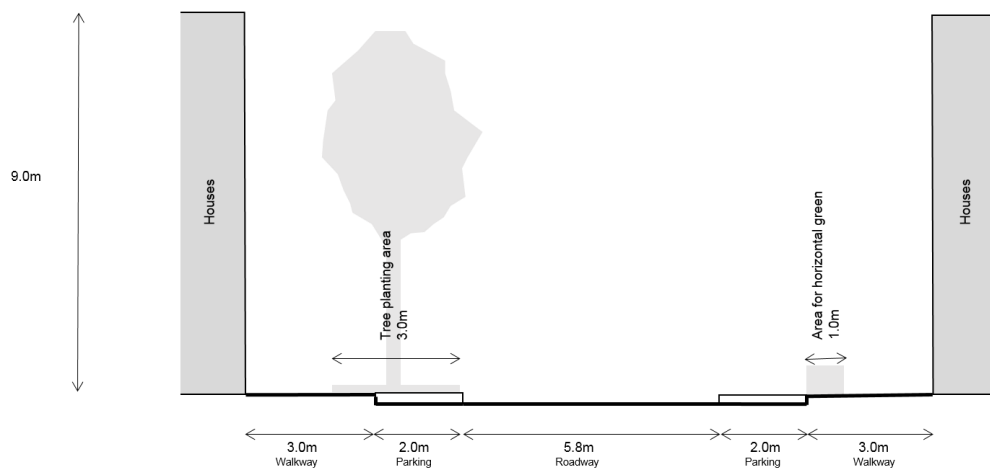
Figure 4.1 Cross section of the virtual street design

Figure 4.2 The virtual environment without any green element

The greenscape elements were then added to the 'empty' street, using generic representations of the elements. The virtual environment did not depict specific species of flowers or trees. The trees could be small (below or at building height, approximately 8 m), large (taller than the buildings, approximately 13 m), or absent. Horizontal green in a strip of one meter wide could be grass, flowers, hedges (approximately 50 cm tall), or be absent. Vertical green could consist of wall climbing plants on the house facades, or be absent.

Figure 4.3 shows some examples of the virtual street with different main elements in different configurations. Appendix A presents larger versions of a selection of the used images. In order to allow more immersion, which could lead to stronger feelings of presence and thereby clearer results, two types of representation were made: a static representation (picture) and an 11-second linear movie clip (video) as if viewers are walking through the fictional street. For both, the camera perspective was set to the eye level of an average Dutch person (1.75m) (Statistics Netherlands, 2015).
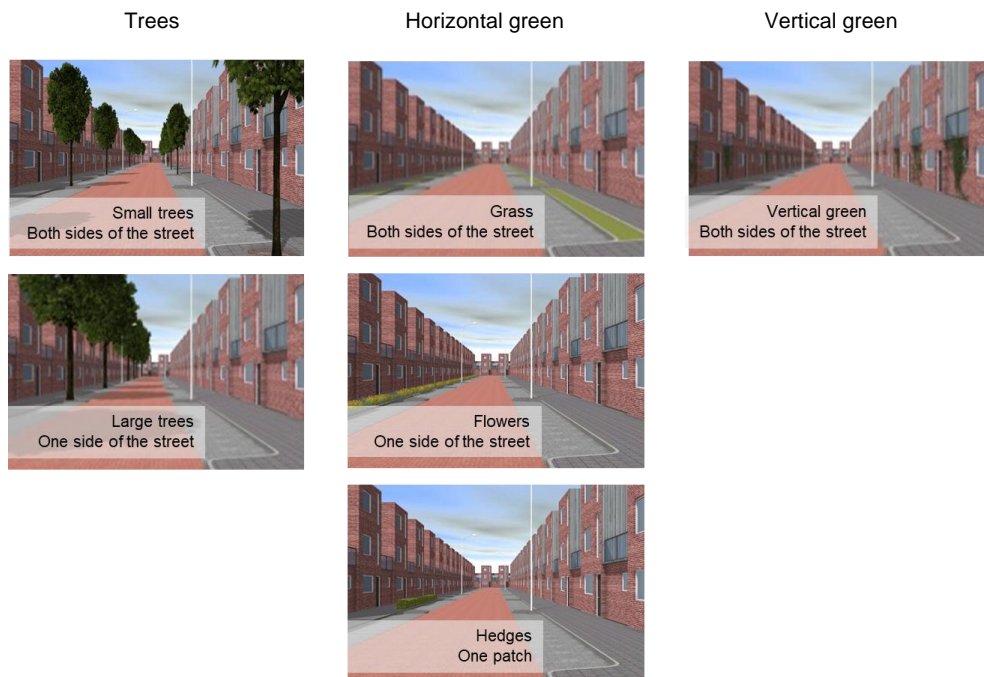
Figure 4.3 Examples of visualizations of street profiles (see appendix A for larger versions)

4.3 Questionnaire

A questionnaire was constructed to collect the data. The questionnaire consisted of four main parts. Part 1 involved questions about the current urban greenscape in the respondent's city, including whether they would like to see any improvements. Parts 2 and 3 concerned the choice experiment (SC) and the restoration likelihood (RL) tasks respectively. Part 4 posed questions about the respondent's socio-demographic background.

The questionnaire was administered to members of the municipal citizen panels of the cities Breda, Eindhoven, 's Hertogenbosch and Tilburg. Using municipal panels meant that the questionnaire had to be in line with the usual surveys about municipal matters, and satisfy the guidelines for approaching the panels. Typically, panel members receive one or two short surveys per month, with only a few questions that take a maximum of 5 minutes. As the current questionnaire required more time and introduced more complexity, there was the risk that respondents would not complete the survey. Furthermore, the local governments put restrictions on the burden imposed on the respondents. The questionnaire reflects these restrictions.

Personnel from the local governments, co-workers at the university, students, friends and family, tested the questionnaire in several rounds. Tests concerned language, understandability, logic, and feasibility (time and effort). Adjustments were made, leading to the final questionnaire. The questionnaires for all four municipal panels differed only in city name and logo and the last question about a follow-up survey. This question was not added for 's Hertogenbosch because the policy on the use of the citizen panel did not allow it. The questionnaire was in Dutch (see Appendix B1 and the English translation in Appendix B2). Preparation, tuning and synchronization with the municipalities required close to a year. The questionnaire was constructed and run using the Berg system (Jessurun, 2014), an online-survey-system of the university research group, which runs on university servers. The questionnaire system was tested on functionality, load and stability. It worked well with all major computer systems (Windows and Apple) and was found suitable for all main web browsers (Internet explorer, Firefox, Chrome, Safari). The system remained stable and smooth even under hundreds of nearly simultaneous access attempts as tested with the help of the software selenium (selenium, 2014).

4.3.1 Part 1: Opinions about the current greenscape design

The questionnaire started with three questions about the current greenscape design in the city and neighborhood of the respondent. At the city level, the questions concerned the current

amount and variation in public green in streets. At the neighborhood level, respondents were asked whether they had suggestions for improving public green in neighborhood streets. These questions were aimed at introducing the topic of research.

4.3.2 Part 2: Choice task

The choice task aimed at assessing the restorative value of the elements, configurations and total greenscape design by having respondents choose between two street profiles. Only the greenscape design varied and the streets had an otherwise identical layout and building design. The respondents were instructed to assume that all other potentially relevant attributes of the streets are identical and thus should be ignored. The street profiles of eight randomly selected profiles were presented with a pivot profile on the left, and the other seven profiles in random order on the right.

In order to have respondents base their choice on restorative value, the choice task was explained and framed as walking home after a busy day. The implied need for restoration is assumed to lead to choosing the urban greenscape design that offers the highest restorative value as all other aspects are kept constant.

Figure 4.4 Screenshot of the choice task (in English translation)

In the next seven questionnaire pages, choice sets of pictures of two street profiles with differing greenscape designs were shown (see Figure 4.4 for an example), accompanied by the following specific task and question (translated from Dutch):

> *"After a busy day you are walking home. Which street do you choose to walk along? (Besides the green design, the streets are the same (for instance in distance)."*

Note that a 'No choice' option was not added because the respondent has only these two options to get home. The formulation walking *along* a street on their way home was used to avoid that responses reflect possible expected negative side effects in the respondent's own residential street such as limited parking space, leaves to clear, or bird poo on his or her car. As respondents were required to view two profiles next to each other, no video option was added.

4.3.3 Part 3: Rating task

The next main task was to rate the same eight profiles in terms of restoration likelihood, in line with Nordh et al. (2009) and Lindal and Hartig (2015). Both research teams asked respondents to which extent they agreed to statements on an 11-point scale, ranging from 'not at all' to 'completely'. The version by Nordh et al. was tailored to fit a (small) park environment, while Lindal and Hartig addressed a residential streetscape. Therefore, Lindal and Hartig's version was considered more suitable for the current research. Addressing the feedback on our test version, small adjustments were made in the final phrasing of the statements in the questionnaire (see Table 4.1 for the statements used).

The questionnaire showed the picture of the profile in the middle of the screen and the five statements below. In this questionnaire, respondents were required to rate the statements on a five-point scale, ranging from 'strongly disagree' to 'strongly agree', rather than an 11-point scale. This was to comply with the requirement of the municipality to use shorter answering scales.

The same scenario as in the stated choice task was used. Some statements may appear less compatible to the scenario of walking through a street, as the statements imply a stay in the street for some period of time. However, walking along an environment also implies experiencing the environment.

Table 4.1 The five statements related to restoration likelihood, in Dutch and English

	Dutch	English	
1	"Ik vind dit een fijne omgeving"	"I like this environment"	Liking
2	"Hier zou ik bij kunnen komen van mijn drukke dag; na een tijdje kan ik dan mijn aandacht er weer beter bij houden"	"I would be able to rest and recover my ability to focus in this environment"	Likelihood of restoration
3	"Hier zijn doorbreekt de dagelijkse routine"	"Spending time here gives me a break from my day-to-day routine"	Being away
4	"Hier ben ik even weg van alles wat aandacht van me vraagt"	"It is a place to get away from the things that usually demand my attention"	Being away
5	"Deze omgeving fascineert me; mijn aandacht wordt getrokken door interessante dingen"	"This place is fascinating; My attention is drawn to many interesting things"	Fascination

For each profile, respondents were asked to rate the street through the following scenario and task:

> *"After a busy day you are walking home through this street. Closely look at the picture and imagine actually being there. You can click on the picture. It will then become a brief video of the street. Rate the following statements:*
> - *I like this environment*
> - *I would be able to rest and recover my ability to focus in this environment*
> - *Spending time here gives me a break from my day-to-day routine*
> - *It is a place to get away from the things that usually demand my attention*
> - *This place is fascinating; My attention is drawn to many interesting things"*

To potentially further improve the accuracy of rating the profiles, respondents had the possibility to get more immersed in the street scene, by using the clickable link to the 11-second movie clip on Vimeo (Vimeo.com, 2013-2019) of 'walking' through the street. Figure 4.5 shows a screenshot of the RL task.

Figure 4.5 Screenshot of the rating task (in English translation)

4.3.4 Part 4: Socio-demographics

In order to explore to what extent people with different backgrounds may differently judge the restorative value and restoration likelihood of urban greenscapes, data on socio-demographic characteristics of the respondents were collected. Respondents were asked to provide information about their gender (male or female), age (in years), education level, household composition, income and ethnic background. The collection of personal information was done based on principles of ethics, such as explaining why the data is needed, applying neutral

phrasing and preventing the possibility that individuals can be identified individually. Moreover, the data are stored securely. In the context of socio-demographic characteristics, a few specifics of Dutch society and resulting answer categories in the socio-demographics need to be discussed. First, the Dutch education system has many levels, and has seen several reforms over the years. To allow all respondents to enter the appropriate highest completed education level, 10 categories were used, including an option to enter a specific other education level. The English translation of the questions (see Appendix B2) shows the answer categories for 'education level' in line with international terminology. Second, income categories on the personal level were defined around the Dutch standards for 'minimum' and 'modal' and included an indication of yearly income before tax in Euros. An explicit 'No answer' category was included as in Dutch culture people do not easily talk about their income. Third, regarding ethnic background, the question was posed in terms of 'What nationality do you consider yourself to have?' instead of 'What is your nationality?' Besides ethical considerations, the reason for phrasing it this way, is that cultural background is not always established best by knowing the person's official nationality. This is especially true for the Dutch situation with a significant share of people with dual citizenship and immigrant backgrounds who may have relatively recently obtained formal Dutch citizenship.

4.4 Administration of the questionnaire and response

In November and early December 2014, the members of the citizen panels were sent an e-mail through the regular municipal channels inviting them to participate in the survey. The e-mail text briefly described the relevance of urban green and the role of local government in this regard. In addition, it introduced the researchers and the nature of the questionnaire (*'The questionnaire has images and video clips of green in urban streets and asks your opinion'*). Next, it explained some practicalities about the questionnaire, including the expected duration of approximately 15 minutes, the advice to use a larger screen than a smart phone and the warning that sometimes questions and pictures of urban green could seem very similar. No data was collected on the actual device and screen size used. The e-mail included a link to the questionnaire on the university server. The participating cities each sent out their own e-mail messages, somewhat differing in wording and layout, but the content was the same.

The respondents were invited on consecutive weekdays for Tilburg, Breda and 's Hertogenbosch and for Eindhoven a week later. This spread was to prevent possible overload of the university server and to fit the planning of the participating cities. The respondents could enter and complete the questionnaire for a period of 21 days.

4.4.1 Response rate

The invitation was sent to a total of 15,204 unique e-mail addresses. The questionnaire was started 6,889 times (45% response rate), more than half of which was on the day of receiving the invitation. The municipality of Breda sent a reminder e-mail after approximately two weeks and the municipality of 's Hertogenbosch after approximately 10 days. Figure 4.6 shows the cumulative number of questionnaire starts (Y-axis) by city over the 21 days that the questionnaire was online. The graph clearly shows the very high response on the first days and big differences in the numbers of responses between cities. These differences are logical considering that the citizen panel of 's Hertogenbosch has the largest number of members, while the panel of Tilburg has the smallest. Table 4.2 shows the details by city.
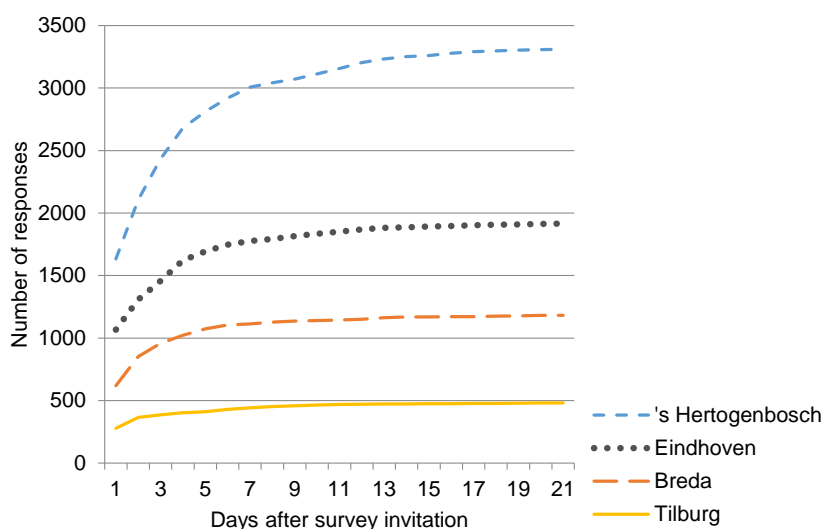
Figure 4.6 Cumulative starts by days after survey invitation for the four participating cities

Table 4.2 Basic statistics on population, panels and response rates

City	Population* (2014/2015)	Panel members (2014)	Number of question-naire starts	Number of completed question-naires	Completed / started (%)	Response (question-naire starts) (%)	Response (question-naires completed) (%)
Breda	180,937	2,849	1,182	873	73.9 %	41.5 %	30.6 %
Eindhoven	223,209	5,100	1,916	1,403	73.3 %	37.6 %	27.5 %
's Hertogenbosch	150,889	6,250	3,310	2,388	72.1 %	53.0 %	38.2 %
Tilburg	211,648	1,005	481	362	75.3 %	47.9 %	36.0 %
Total	766,683	15,204	6,889	5,026	73.0 %	45.3 %	33.1 %

* Source for Population: Statistics Netherlands, 2015

Of the questionnaires started, 5,026 were fully completed (73%). Approximately 20% did not finish the choice task. Figure 4.7 shows the number of respondents progressing through the different parts of the questionnaire. Our expectation that respondents would take the time to fully complete the questionnaire, when they had already done the hardest parts 2 and 3, did not entirely come true. The loss of participants in the last part of the questionnaire was larger than in parts 2 and 3. The respondents from Breda, Eindhoven and Tilburg had the additional question on willingness to participate in follow up research. For these cities, of the 2,638 respondents who completed all previous parts of the questionnaire 1,132 respondents left their e-mail address to participate in further research (Breda: 398, Eindhoven: 576, Tilburg: 158).
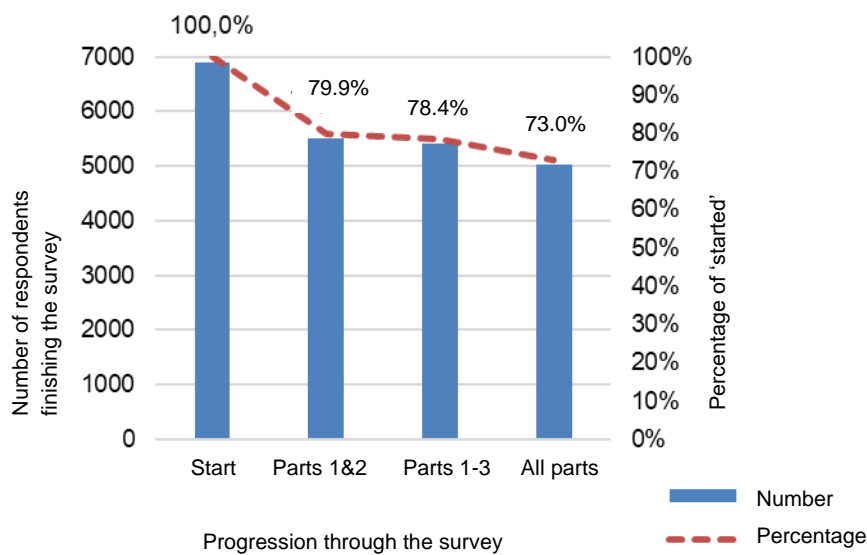
Figure 4.7 Number of and percentage respondents completing questionnaire parts
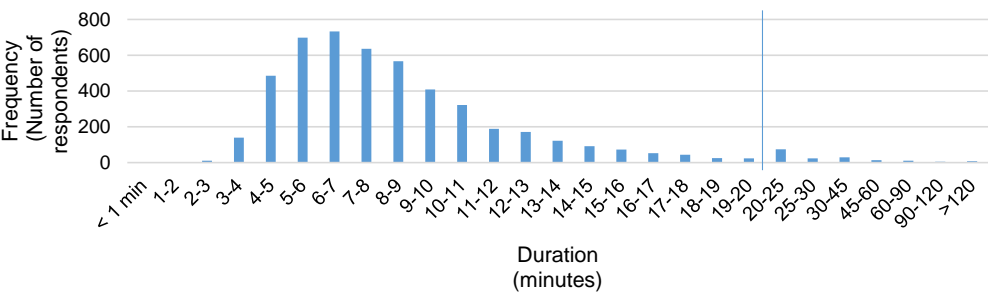
Figure 4.8 Histogram of duration of completing the survey

On average, the included respondents spent nine minutes (mean 8:58mins; sd 6:27mins) on completing the questionnaire, leaving eight respondents who took more than three hours to complete the questionnaire out of the calculation of this average. Note that outlying respondents were only removed for calculating this average time spent; respondents were not removed from the analysis based on taking long to finish the questionnaire. Some of these outliers spent more than 24 hours on finishing the questionnaire, indicating they probably stopped for some time and chose to finish the questionnaire some other time. Most respondents spent between 4 and 11 minutes on the questionnaire, which is longer than usual for other surveys in the citizen panels and less than the estimated 15 minutes. Figure 4.8 shows the number of respondents per one-minute category for durations below 20 minutes, and for duration longer than 20 minutes, per 5, 15, or 30 minutes. The 20-minute mark is shown through a vertical line. Last, judging by the very low amount of questions and remarks mailed to us, the university survey system used for data collection can be considered very stable and user friendly.

4.4.2 Quality checks and data preparation

The data were checked for illogical responses. The data of three respondents were deleted due to impossible answers. In case of likely typing errors, the error was replaced with a 'missing value' and the respondent was kept in the data set. Due to open-ended questions and the option to enter 'other categories', some data needed to be prepared before analysis. In these cases, the answers were reviewed and where possible assigned into one of the existing categories. If not possible, the answer remained in the category 'Other'. After checking the data, 4,956 fully completed questionnaires remained for further analysis. For the analysis, some variables and variable levels were recoded or aggregated (age to age groups, using Levene's test; education level aggregated in levels low, medium and high; income aggregated to lower for modal and below, and higher for above modal).

Moreover, as profiles were randomly selected, a check was performed whether all attribute levels were sufficiently balanced across all offered profiles. Of the tree variable, the possible levels were presented 9,912 times on average, with a maximum of 10,100 and a minimum of 9.830. Of the horizontal green variable, the possible levels were presented 6,938 times on average, with a maximum of 7,269 and a minimum of 6,703. Of the vertical green variable, the possible levels were presented 17,346 times on average, with a maximum of 17,435 and a minimum of 17,285. These large numbers with limited differences suggest sufficient balance.

4.4.3 Sample socio-demographics

The sample consisted of 4,956 citizens. Some main socio-demographic characteristics of the sample are an average age of 55.4 years, a proportion of 61% males and a proportion of 61.7% having finished higher education. Corresponding with the proportion of respondents having completed higher education level, income levels are medium to high for approximately half of the sample and for a further 20% no income information was supplied by respondents choosing the 'no answer' option. Figures 4.9 to 4.11 provide further details of the respondents' socio-demographics. The group of respondents was different from the actual (adult[2]) population of the cities (based on Statistics Netherlands, 2015) in regard to gender (61% male vs 49.7%), age (average 55.4 versus 48.9) education level (61.7% versus 31.7% high education level (for ages 15-75)). Very few respondents considered themselves non-Dutch (1.6%) compared to the official 6.5%. The sample from a total combined population of the four cities of 766,683 of which 717,202 Dutch citizens (Statistics Netherlands, 2015) thus showed a bias. This was expected because the municipal panels tend to introduce a bias towards citizens willing to participate in municipal surveys, which may be an indicator of societal involvement and participation. The municipalities confirmed that the sample socio-demographics were in line with the socio-demographic characteristics of the panel members, but could not give further details about the specific statistical distributions of the panel because of privacy reasons and consent.
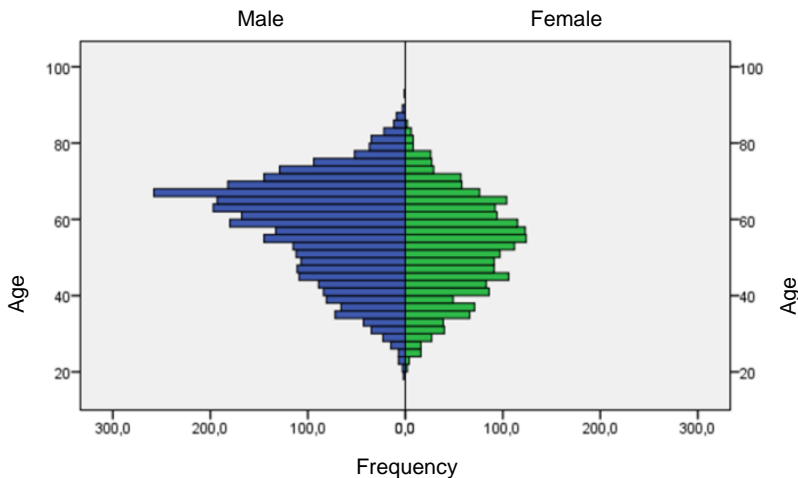
Figure 4.9 Gender and age distribution of the respondents

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[2] As the research excluded children, to make a fair comparison, the averages of the *adult* population in the cities in 2015 was used, based on data from Statistics Netherlands (2015). The reference percentage high education level is based on the available statistics of the population 15-75 years old.
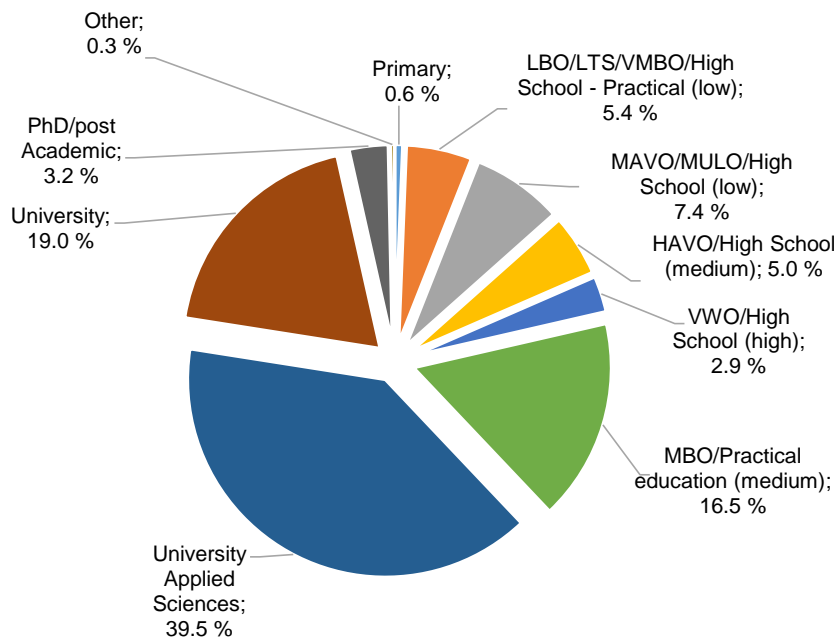
Figure 4.10 Respondents per education level
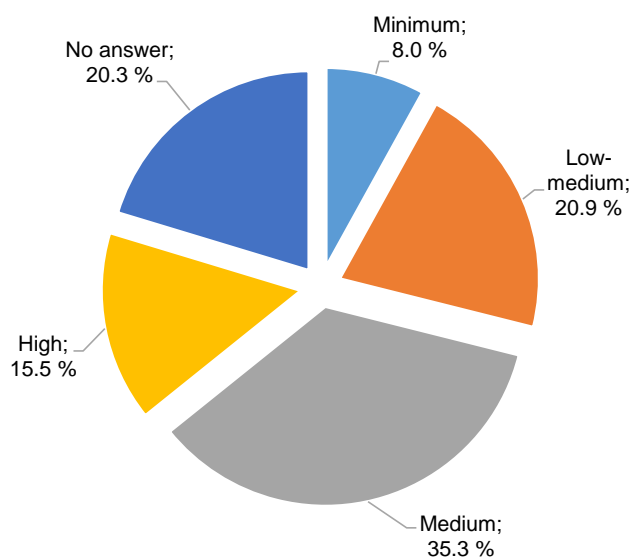
Figure 4.11 Respondents per income level

4.5 Conclusions

The details of the operationalization of the study were presented. The study employed an online questionnaire using controlled fictional virtual environments in which the urban context of the urban greenscape was kept constant. A 3D virtual urban residential street environment was created, in which the 280 different greenscape designs were incorporated. Municipal panels were used to collect the data. Preliminary analyses indicate good data quality. However, a bias towards certain population groups is present in the sample. This should not have major implications for the current study, but limits generalizability to the population of the participating cities, or the general Dutch population.

Chapter 5

Analyses and results

5.1 Introduction

As the urban greenscape is assumed to provide a restorative value to citizens, the study was designed to specifically assess the contribution of green elements and configurations at the street level to the restorative value of the urban living environment. The study examines the restorative value of the urban greenscape using choice experiments and restoration likelihood ratings. The online questionnaire provided a large dataset. Nearly 5,000 respondents made choices, each involving 7 x 2 street profiles, leading to close to 70,000 data points from the choice task. The respondents each rated 8 street profiles, leading to close to 40,000 data points in terms of restoration likelihood. This chapter reports the results of the analyses.

First, the results of the analyses of the stated choice data are presented. Model estimation results are described and the resulting model is interpreted. The main and interaction effects, as well as the influence of socio-demographic variables are discussed. Second, the results of the analyses of the restoration likelihood rating data are presented. As for the stated choice data, the results of the model estimation are described, the findings are interpreted and the main and interaction effects, as well as the influence of socio-demographic variables, are discussed. In addition, the restoration likelihood rating task included the option to view a brief video clip, illustrating 'walking through the street', aimed at offering more immersion within a virtual environment. The use of this option is discussed. Last, the relationship between restoration likelihood and the stated choices is explored by analyzing the extent to which the stated choices can be predicted by the restoration likelihood ratings.

5.2 Stated choices[3]

In order to measure the restorative value of street profiles and the contribution of constituent greenscape elements and configurations, respondents were asked to choose from a series of

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[3] Parts of this section are based on Van Dongen, R.P. and Timmermans, H.J.P., 2019, Preference for different urban greenscape designs: A choice experiment using virtual environments, *Urban Forestry and Urban Greening*, 44 (126435). https://doi.org/10.1016/j.ufug.2019.126435

binary choice sets, the street profile they would choose walking home when in need of restoration. Consequently, it is assumed that respondents' choices reflect the restorative value of the street profiles while walking along the road. A mixed logit model was estimated, assuming that the observed choices reflect the differences in restorative values of the profiles, while accounting for unobserved heterogeneity by estimating random parameters for (some of) the attributes levels.

5.2.1 Data check

For each respondent, eight out of the 280 different profiles, representing a specific greenscape design, were randomly selected. Seven choice sets of two profiles were presented consecutively in random order to avoid any order effects. This way, a total of 69,384 street profiles were presented to respondents in the experiment. The two profiles in each choice set were shown horizontally next to each other (left - right). However, for each respondent, the choice task always showed the same profile in the left picture as the pivot and the seven others in the right picture. Therefore, of the eight randomly selected profiles, one profile was presented seven times and the seven others once. The fact that the left picture remained the same for all seven choice tasks for each respondent may induce differential familiarity with the profiles. Furthermore, respondents may show a tendency to systematically choose either the left or the right picture. To check whether there was evidence of a familiarity effect or a left-right tendency, the number of times the left and right picture was chosen was calculated. With the random selection of profiles and the absence of a familiarity effect, the number of choices of the left picture is expected to be approximately half of the choices. Table 5.1 shows that of the 34,692 choices made, indeed nearly half concerned the left and nearly half the right picture. Results, broken down by city, show similar results, leading to the conclusion that there is no indication of systematically choosing the right or left picture.

Table 5.1 Number of times the left and right picture was chosen

City	Number of choice sets	Number of times left picture was chosen (%)	Number of times right picture was chosen (%)
Breda (B)	6,048	2,977 (49.2%)	3,071 (50.8%)
Eindhoven (E)	9,583	4,831 (50.4%)	4,752 (49.6%)
's Hertogenbosch (H)	16,534	8,297 (50.2%)	8,237 (49.8%)
Tilburg (T)	2,527	1,239 (49.0%)	1,288 (51.0%)
TOTAL	34,692	17,344 (50.0%)	17,348 (50.0%)

5.2.2 Model estimation

NLOGIT5 (Econometric Software Inc., 2012) was used for model estimation. The urban greenscape variables are categorical. Coding is therefore needed. Because a profile without any green is a natural benchmark, dummy coding was used (see appendix D). Dummy coding allows the comparison of the profiles with a reference or base profile, which in this case was the street with no green elements at all. Estimated parameter values, therefore, directly depict the contribution of the attribute levels, i.e., the varied urban greenscape elements and configurations, to the estimated restorative value of the street profile. The estimated interaction effects indicate to what extent the corresponding combination of attribute levels increase or decrease the sum of the main effects of these attribute levels. To accommodate heterogeneity in restorative value, a mixed logit model was estimated. This model captures unobserved heterogeneity in restorative value by allowing (some of) the parameters β_{kl} to be random with an estimated mean and variance for some assumed distribution.

Random parameters were assumed for the main effects. As SRT and ART state that nature has a positive restorative value, adding urban green elements to an environment is thus expected to have a positive effect on the restorative value of that environment. Setting the street without any green elements as the base profile therefore means that only positive main effects are expected. Therefore, the LogNormal distribution was chosen to capture unobserved heterogeneity in the contribution of the attribute levels to the restorative value of a street profile. Transformation from the log-values estimated by NLOGIT to the real numbers for the effects is then achieved through (Hensher et al., 2015):

$$\mu_{\beta'_i} = e^{\left(\beta_i + \frac{\sigma_i^2}{2}\right)}$$ (where β_i is the estimated parameter for attribute level i)

Furthermore, because the experimental task required respondents to make seven choices, panel effects were considered in the estimation. The estimated main effects and significant interaction effects are presented in Table 5.2 and shown graphically in Figure 5.1. The model has a ρ^2_{adj} (adjusted McFadden pseudo ρ^2) of .505 (n = 34,692, panel effects, using 1,000 Halton draws and a LogNormal distribution for the random effects). In choice modeling, values of ρ^2 between .2 and .4 are considered to be very good (McFadden, 1978), implying the estimated model fits the data very well. Furthermore, the standard deviations around the LogNormal means are significant ($p < .05$), except for one patch of grass, suggesting unobserved heterogeneity in the contribution of these attributes to the restorative value of the urban greenscape. Moreover, ρ^2_{adj} for the corresponding multinomial logit model (MNL), which is the base model without accommodating heterogeneity, is .432, which suggests significant heterogeneity.

Table 5.2 Parameter estimates of the Mixed Logit model

Variable code	Variable	Log-Normal	Sig.	St.dev. Log-Normal	Sig.	Parameter	Mean value after transformation	
Main effects								
Tsc	Small tree single	-0.622	0.244	**0.997**	**0.000**	β1	.882	
Tsl1	Small trees 1 side	**1.753**	**0.000**	**0.222**	**0.000**	β2	**5.913**	
Tsl2	Small trees 2 sides	**2.289**	**0.000**	**0.366**	**0.000**	β3	**10.549**	
Tlc	Large tree single	**0.902**	**0.000**	**0.296**	**0.000**	β4	**2.575**	
Tll1	Large trees 1 side	**2.098**	**0.000**	**0.297**	**0.000**	β5	**8.520**	
Tll2	Large trees 2 sides	**2.782**	**0.000**	**0.771**	**0.000**	β6	**21.736**	
Gc	Grass single patch	-6.737	0.203	3.581	0.092	β7	.723	Random parameters
Gl1	Grass 1 side	-1.833	0.055	**1.678**	**0.001**	β8	.654	
Gl2	Grass 2 sides	**0.930**	**0.000**	**0.607**	**0.000**	β9	**3.046**	
Fc	Flowers single patch	0.178	0.614	**0.636**	**0.000**	β10	1.464	
Fl1	Flowers 1 side	**1.008**	**0.000**	**0.400**	**0.000**	β11	**2.969**	
Fl2	Flowers 2 sides	**1.704**	**0.000**	**0.491**	**0.000**	β12	**6.199**	
Hc	Hedges single patch	-0.984	0.130	**1.039**	**0.000**	β13	.641	
Hl1	Hedges 1 side	**1.224**	**0.000**	**0.231**	**0.004**	β14	**3.492**	
Hl2	Hedges 2 sides	**1.889**	**0.000**	**0.551**	**0.000**	β15	**7.701**	
Vc	Vertical green single	-0.924	0.132	**1.041**	**0.001**	β16	.682	
Vl1	Vertical green 1 side	**-2.881**	**0.015**	**2.008**	**0.001**	β17	**.421**	
Vl2	Vertical green 2 sides	0.260	0.219	**0.708**	**0.000**	β18	1.667	

First order interaction effects							Value	St. err.	Significance
Tsc x Gl1	Small tree single AND Grass 1 side					β20	**1.553**	**.445**	**.001**
Tsc x Gl2	Small tree single AND Grass 2 sides					β21	**1.275**	**.548**	**.020**
Tsc x Fc	Small tree single AND Flowers single					β22	**1.181**	**.530**	**.026**
Tsc x Fl2	Small tree single AND Flowers 2 sides					β24	**1.483**	**.637**	**.020**
Tsc x Hc	Small tree single AND Hedges single					β25	**1.859**	**.516**	**.000**
Tsc x Vc	Small tree single AND Vertical green one side					β28	.850	.458	.064
Tsc x Vl2	Small tree single AND Vertical green 2 sides					β30	**1.363**	**.460**	**.003**
Tsl1 x Gl2	Small trees 1 side AND Grass 2 sides					β33	-1.103	.650	.089
Tsl1 x Hl1	Small trees 1 side AND Hedges 1 side					β38	**-1.121**	**.563**	**.046**
Tsl1 x Hl2	Small trees 1 side AND Hedges 2 sides					β39	**-1.523**	**.674**	**.024**
Tsl2 x Fl1	Small trees 2 sides AND Flowers 1 side					β47	**-1.430**	**.661**	**.031**
Tsl2 x Fl2	Small trees 2 sides AND Flowers 2 sides					β48	**-1.970**	**.787**	**.012**
Tsl2 x Hl1	Small trees 2 sides AND Hedges 1 side					β50	**-2.158**	**.576**	**.000**
Tsl2 x Hl2	Small trees 2 sides AND Hedges 2 sides					β51	**-2.203**	**.803**	**.006**
Tsl2 x Vc	Small trees 2 sides AND Vertical green single					β52	-.980	.533	.066
Tlc x Hc	Large tree single AND Hedges single					β61	1.000	.525	.057
Tll1 x Gl2	Large trees 1 side AND Grass 2 sides					β69	**-1.173**	**.588**	**.046**
Tll1 x Fc	Large trees 1 side AND Flowers single					β70	**-1.364**	**.606**	**.024**
Tll1 x Fl1	Large trees 1 side AND Flowers 1 side					β71	**-1.222**	**.604**	**.043**
Tll1 x Fl2	Large trees 1 side AND Flowers 2 sides					β72	-1.284	.770	.095
Tll1 x Hl1	Large trees 1 side AND Hedges 1 side					β74	**-2.544**	**.552**	**.000**
Tll1 x Hl2	Large trees 1 side AND Hedges 2 sides					β75	**-3.291**	**.653**	**.000**
Tll2 x Gc	Large trees 2 sides AND Grass single					β79	**-1.184**	**.590**	**.045**

TlI2 x GI2	Large trees 2 sides AND Grass 2 sides	β81	**-2.193**	**.671**	**.001**
TlI2 x FI1	Large trees 2 sides AND Flowers 1 side	β83	**-2.574**	**.785**	**.001**
TlI2 x FI2	Large trees 2 sides AND Flowers 2 sides	β84	**-3.378**	**.809**	**.000**
TlI2 x HI1	Large trees 2 sides AND Hedges 1 side	β86	**-2.976**	**.726**	**.000**
TlI2 x HI2	Large trees 2 sides AND Hedges 2 sides	β87	**-5.543**	**.821**	**.000**
TlI2 x Vc	Large trees 2 sides AND Vertical green single	β88	**-2.282**	**.592**	**.000**
TlI2 x VI1	Large trees 2 sides AND Vertical green 1 side	β89	**-1.239**	**.592**	**.036**
TlI2 x VI2	Large trees 2 sides AND Vertical green 2 sides	β90	**-1.799**	**.665**	**.007**
Gc x Vc	Grass single AND Vertical green single	β91	**-1.466**	**.653**	**.025**
GI2 x Vc	Grass 2 sides AND Vertical green single	β97	-1.070	.556	.055
GI2 x VI2	Grass 2 sides AND Vertical green 2 sides	β99	-1.022	.592	.084
Hc x VI1	Hedges single AND Vertical green 1 side	β110	**.991**	**.492**	**.044**
HI1 x VI1	Hedges 1 side AND Vertical green 1 side	β113	-.792	.455	.082
HI2 x Vc	Hedges 2 sides AND Vertical green single	β115	**-1.901**	**.670**	**.005**
Second order interaction effects			Value	St. err.	
Tsc x Gc x VI1	Small tree single AND Grass single AND Vertical green 1 side	β119	1.510	.917	.100
Tsc x GI1 x VI2	Small tree single AND Grass 1 side AND Vertical green 2 sides	β123	**-2.013**	**.771**	**.009**
Tsc x Fc x VI2	Small tree single AND Flowers single AND Vertical green 2 sides	β129	**-2.299**	**.854**	**.007**
Tsc x Hc x VI1	Small tree single AND Hedges single AND Vertical green 1 side	β137	-1.677	.872	.054
Tsc x Hc x VI2	Small tree single AND Hedges single AND Vertical green 2 sides	β138	**-1.835**	**.812**	**.024**
Tsc x HI1 x VI2	Small tree single AND Hedges 1 side AND Vertical green 2 side	β141	-1.497	.821	.068
Tsl1 x GI2 x Vc	Small trees 1 side AND Grass 2 sides AND Vertical green single	β151	**2.255**	**.988**	**.023**
Tsl1 x HI2 x Vc	Small trees 1 side AND Hedges 2 sides AND Vertical green single	β169	1.992	1.038	.055
Tsl2 x GI2 x Vc	Small trees 2 sides AND Grass 2 sides AND Vertical green single	β178	1.680	.903	.063
Tsl2 x FI1 x Vc	Small trees 2 sides AND Flowers 1 side AND Vertical green single	β184	1.820	.976	.062
Tsl2 x FI1 x VI1	Small trees 2 sides AND Flowers 1 side AND Vertical green 1 side	β185	1.865	.982	.058
Tsl2 x HI1 x Vc	Small trees 2 sides AND Hedges 1 side AND Vertical green single	β193	**1.762**	**.857**	**.040**
Tsl2 x HI1 x VI1	Small trees 2 sides AND Hedges 1 side AND Vertical green 1 side	β194	**2.183**	**.840**	**.009**
Tsl2 x HI1 x VI2	Small trees 2 sides AND Hedges 1 side AND Vertical green 2 sides	β195	1.576	.958	.100
Tlc x Hc x VI1	Large tree single AND Hedges single AND Vertical green 1 side	β218	**-1.844**	**.821**	**.025**
Tlc x HI2 x Vc	Large tree single AND Hedges 2 sides AND Vertical green single	β223	1.634	.954	.087
TlI2 x Gc x Vc	Large tree 2 sides AND Grass single AND Vertical green single	β253	**3.092**	**1.033**	**.003**
TlI2 x Gc x VI1	Large tree 2 sides AND Grass single AND Vertical green 1 side	β254	1.715	.990	.083
TlI2 x GI2 x Vc	Large tree 2 sides AND Grass 2 sides AND Vertical green single	β259	**2.705**	**1.011**	**.007**
TlI2 x GI2 x VI2	Large tree 2 sides AND Grass 2 sides AND Vertical green 2 sides	β261	**2.990**	**1.176**	**.011**
TlI2 x Fc x Vc	Large tree 2 sides AND Flowers single AND Vertical green single	β262	1.864	1.086	.086
TlI2 x FI2 x Vc	Large tree 2 sides AND Flowers 2 sides AND Vertical green single	β268	**3.481**	**1.217**	**.004**
TlI2 x HI1 x Vc	Large tree 2 sides AND Hedges 1 side AND Vertical green single	β274	**2.622**	**1.034**	**.011**
TlI2 x HI1 x VI1	Large tree 2 sides AND Hedges 1 side AND Vertical green 1 side	β275	1.726	.971	.076
TlI2 x HI2 x Vc	Large tree 2 sides AND Hedges 2 sides AND Vertical green single	β277	**2.916**	**1.161**	**.012**
TlI2 x HI2 x VI2	Large tree 2 sides AND Hedges 2 sides AND Vertical green 2 sides	β279	2.043	1.138	.073

Effects with significance levels < .05 are marked in bold. Effects with significance level ≥ 0.10 are omitted for overview.

ρ^2_{adj} = 0.505 (McFadden)
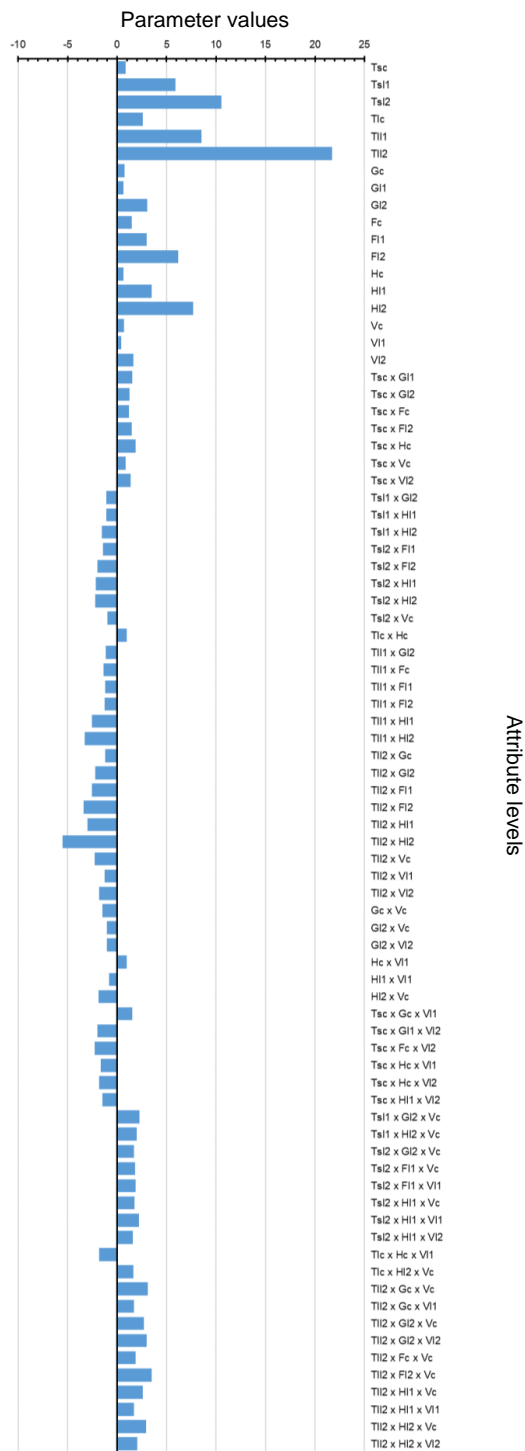
Figure 5.1 Graphic representation of the parameter values of the ML model

5.2.3 Main and interaction effects

The estimated contribution of greenscape elements and their configurations to the restorative value of a street profile is represented by the corresponding parameter values. Main and interaction effects are described.

Main effects

Double rows of large trees contribute most to the restorative value of the urban greenscape, followed by double rows of small trees and a single row of large trees. The further ranking of elements and configurations from high to low restorative values is: hedges and flowers along both sides of the street, small trees and hedges along one side, grass along both sides, flowers along one side, one large tree, and vertical green along one side of the street (example images with (combinations of) the elements and configurations can be found in appendix A). The values for the concentric configuration, except for large trees, are not significant (at $p < .05$), suggesting that designing residential streets with only one green element or patch of green is not very effective in providing restorative value. Similarly, the values for grass along one side and vertical green along both sides of the street are not significant (at $p < .05$). For all configurations, values for large trees are always higher than values for small trees, the element type with the second highest contribution.

The presence of only double rows of large trees contributes more to the restorative value of the urban greenscape than any combination of other elements and configurations. Vertical green has the lowest restorative value and only vertical green along one side of the street has a restorative value significantly different than zero. It has the smallest restorative value of all element types for the one sided configuration.

Interaction effects

With a few exceptions, the interaction effects are relatively small. Most interactions are not significant; only 29 first order interactions and 13 second order interactions out of 261 possible (first and second order) interactions are significant (at $p < .05$). Interactions between elements and configurations with large main effects typically show relatively larger (negative) interaction effects, most notable for combinations of hedges or flowers in linear configurations with trees in linear configurations. The largest interaction effect is -5.543 for the combination of large trees plus hedges along both sides of the street. Most interaction effects have smaller values than the main effects for the constituting elements and configurations of the interaction. The mostly negative values for the first order interaction effects suggest that combining (two) different elements has a marginally decreasing added restorative value: the (two) main effects

add up to a higher value, but the interaction effect reduces this to some extent. Combining additional green elements thus seems to lead to smaller increases in restorative value.

In some cases, however, the (negative) first and second order interaction effects exceed one or more of the main effects of the constituting elements, effectively leading to a reduction in the total restoration likelihood value of the greenscape design. This is the case mostly when the interaction involves low intensity elements and configurations (especially vertical green) with high intensity elements and configurations (especially trees). Particularly for the second order effects, this occurs mostly with single small trees. More green in such cases leads to less restorative value. This is unexpected for urban residential environments where greenery is rarely considered to be 'too much' and research tends to find a positive restorative effect of increased greenery (e.g., Cox, Shanahan et al., 2017; Dzhambov et al., 2019). A specific pattern is visible in that the significant first order effects have positive values when combining singular small trees, and negative values for almost all other combinations. In contrast, the significant second order effects mostly have negative values when combining singular small trees, and positive values for almost all other combinations. The element type and configuration 'single small tree' therefore seems to be perceived significantly different in interactions than the other element types and configurations. Overall though, the impact of interactions is relatively small and diffuse.

Relative importance

The importance of the attributes can be interpreted relative to each other (Hensher et al., 2015) by calculating the range between the highest and the lowest parameter value within an attribute and then dividing that range by the sum of all ranges. As the attribute level 'not present' is dummy coded as the reference (value of 0) for the main effects, the range for the main effects is established by taking the largest parameter value since the LogNormal distribution assures no negative values are possible. Table 5.3 shows the relative importance of the three attributes trees, horizontal green and vertical green. Trees clearly stand out as the most important greenscape element with a relative importance of nearly 70%. Vertical green is of lowest relative importance at 5%. The large potential of trees is in line with the literature (e.g. Astell Burt & Feng, 2019).

Table 5.3 Relative importance of the attributes (ML model)

	Attribute	Range	Relative importance
Main effects	Trees	21.736	69.9%
	Horizontal green	7.701	24.8%
	Vertical green	1.667	5.4%

5.2.4 Greenscape intensities

Figure 5.2 shows a visualization of the main effects by element type on the y-axis for each configuration (concentric (c), linear along one side of the street (l1) and linear along both sides of the street (l2)) on the x-axis. The graph indicates that the main effects increase depending on two factors. First, an increasing number of elements in the configuration leads to an increase in restorative value (low values for concentric (c), medium values for linear along 1 side (l1) and high values for linear along 2 sides (l2)). Second, an increase in size or scale of the element itself leads to an increase in the restorative value (ranging from the highest values for large trees, to the lowest values for grass and vertical green).

Configurations →	c	l1	l2
Large trees	2.57522	8.51971	21.73646
Small trees	0.88166	5.91316	10.54937
Hedges	0.64130	3.49220	7.70130
Flowers	1.46358	2.96851	6.19923
Grass	0.72268	0.65447	3.04616
Vertical Green	0.68209	0.42140	1.66677
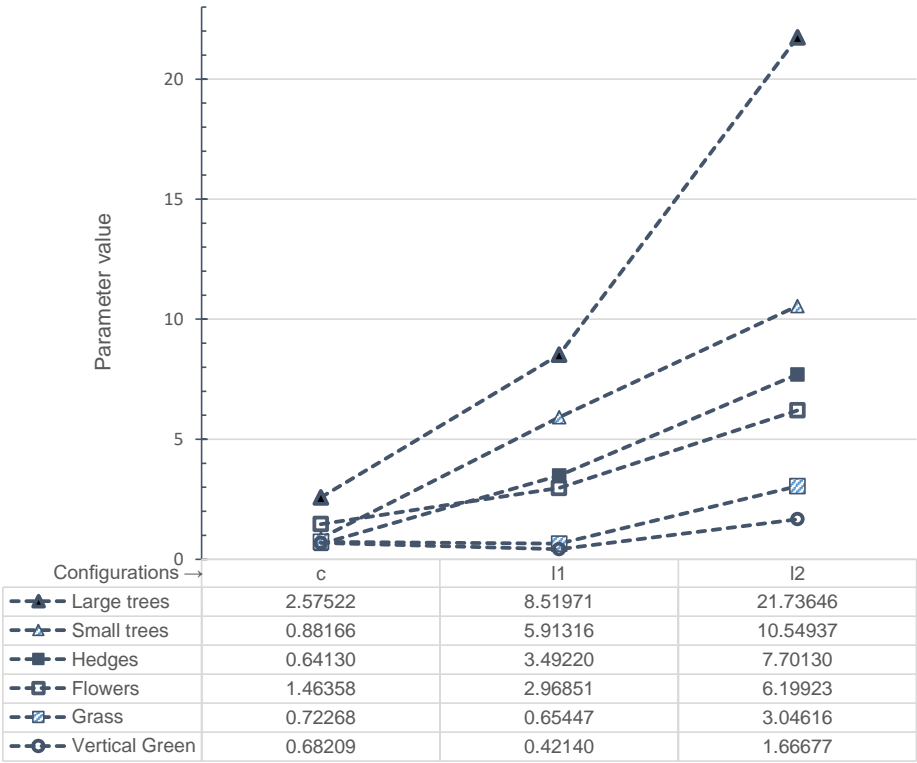
Figure 5.2 Estimated main effects by element and configuration (ML model) (c = concentric or single; l1 = linear along one side of the street; l2 = linear along both sides of the street). Note that the effects for the concentric/single configuration (c) are only significant for large trees, and that the effect for grass along one side and for vertical green along both sides of the street are not significant (p < .05).

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Based on Figure 5.2, the concept of greenscape intensity is introduced as a measure of impact of the urban greenscape. Greenscape intensity is derived from both the elements and the configuration. Elements with high impact, such as trees, have a high element intensity, hedges and flowers have medium impact and medium element intensity, while elements with low impact, such as grass or vertical green, have low element intensity. Likewise, the configuration along both sides of the street has high configuration intensity, the configuration along one side has medium configuration, while the singular configuration has low configuration intensity. The concept of greenscape intensity thus consists of element and configuration intensity and can be visualized on two axes in a 3D-space, plotting the estimated restorative values (main effects) by configuration and element (Figure 5.3).

The concept of greenscape intensity integrates separate elements and configurations into a higher order and more abstract measure for the urban greenscape, while the purpose of the study is to distinguish the restorative values of the elements constituting the urban greenscape. In order to test whether distinguishing the separate greenscape elements leads to improved insight into the restorative value of the greenscape design, over only looking at the holistic amount of (visible) green in the street, an additional model was estimated using the percentage of the picture covered by urban green elements as dependent variable. MATLAB (Mathworks, 2015), more specifically, the module *Colorthreshholder* was used to calculate that percentage by applying sliding scales to filter colors, leaving only the natural elements visible in the picture.
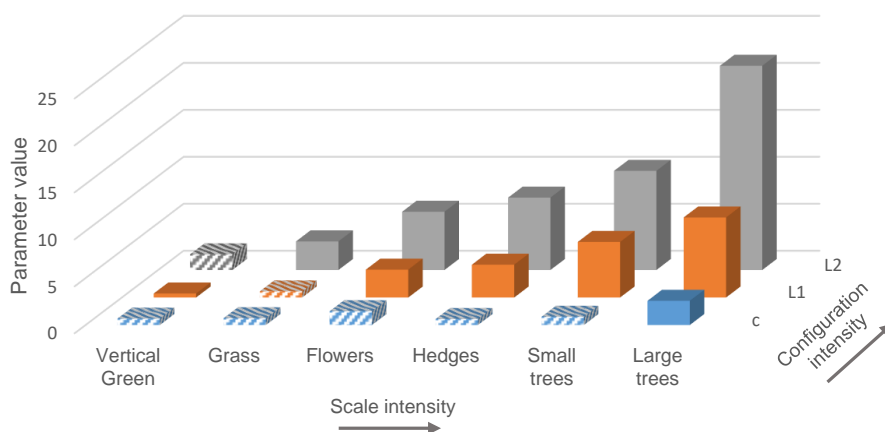
Figure 5.3 Greenscape intensities in two dimensions in relation to the main effects for restorative value. The patterned bars indicate non-significant values (at p < .05).

The ML-model using only the percentage of the picture covered by natural elements estimated a significant and positive parameter value for that percentage. This means that a larger percentage of the picture being covered by natural elements leads to a higher restorative value of the total urban greenscape design. The ρ^2_{adj} value for the model is .403, which has lower fit than the fit of the model distinguishing the separate elements. The Loglikelihood ratio test statistic (sometimes also referred to as 'G2') tests for significance, where G2 = -2 ((LL of model 1) - (LL of model 2)). This test statistic is asymptotically Chi-square distributed with k degrees of freedom, where k is equal to the number of free parameters (Theil, 1971). The test shows that the model with the separate elements significantly outperforms the model based on the percentage visible natural elements (G2 = 5068.95; P(Chi-square (5069; 296) is significant, p = 0.000)).

5.2.5 Heterogeneity in the means of the random parameters

Mixed logit modeling takes unobserved heterogeneity across respondents into account by estimating random parameters around a mean, rather than estimating fixed parameters. The estimated model showed significant estimated standard deviations around the means, except for the single patch of grass, indicating that such heterogeneity exists.

Heterogeneity in the means of the random parameters for the main effects was further examined for systematic sources of heterogeneity (Hensher et al., 2015) by estimating a new mixed logit model with the means of the random parameters (which were the main effects only) as a function of respectively gender, age, education level and income. By including all main effects and socio-demographic characteristics simultaneously in the model, effectively, this incorporates into the model the interaction effects between the attributes and the socio-demographic characteristics of the respondents. The values for these interaction effects indicate whether the log-normal values for the main effects are different (lower for negative sign; higher for positive sign) for the corresponding categories of the dummy coded socio-demographic characteristics. Results are presented in Table 5.4.

Gender

Significant differences between males and females are found for several of the means. Results consistently indicate that females, on average, attribute more restorative value to urban greenscape elements in general, and to trees in particular. For low intensity greenscape elements and configurations, gender differences are not significant.

Table 5.4 Estimated differences in the mean of the random parameters by socio-demographic characteristics

Variable		Para-meter	Gender (*male* is ref. level)	Age (*61+* is reference level)		Education level (*high* is reference level)		Income level (*no answer* is reference level)	
			Female	40 and below	41-60	Low	Medium	Low	High
Tsc	Small tree single	β1	0.021	0.085	**0.224**	0.016	0.027	0.143	**0.313**
Tsl1	Small trees 1 side	β2	**0.162**	0.099	**0.181**	-0.132	**-0.116**	-0.056	0.093
Tsl2	Small trees 2 sides	β3	**0.218**	0.085	**0.198**	**-0.169**	**-0.129**	-0.011	**0.189**
Tlc	Large tree single	β4	**0.167**	**0.224**	**0.314**	-0.116	-0.068	0.113	**0.198**
Tll1	Large trees 1 side	β5	**0.220**	0.079	**0.164**	**-0.224**	**-0.108**	0.124	0.239
Tll2	Large trees 2 sides	β6	**0.275**	0.016	0.102	**-0.534**	**-0.335**	0.235	0.281
Gc	Grass single patch	β7	-1.541	1.259	1.513	3.022	1.505	-0.316	-1.164
Gl1	Grass 1 side	β8	0.031	-4.220	7.940	-5.576	-1.307	-7.350	3.853
Gl2	Grass 2 sides	β9	0.177	0.038	0.205	-0.077	-0.127	**0.389**	**0.326**
Fc	Flowers single patch	β10	**0.421**	-0.180	-0.023	-0.053	-0.075	-0.100	0.208
Fl1	Flowers 1 side	β11	0.166	-0.011	0.000	-0.083	-0.098	0.023	0.024
Fl2	Flowers 2 sides	β12	**0.224**	-0.007	0.107	**-0.205**	**-0.184**	0.088	0.093
Hc	Hedges single patch	β13	-0.098	-0.174	**0.512**	0.233	0.102	0.044	0.299
Hl1	Hedges 1 side	β14	0.069	0.130	0.124	-0.182	-0.096	0.231	0.224
Hl2	Hedges 2 sides	β15	**0.321**	0.088	0.115	-0.054	0.003	0.087	**0.249**
Vc	Vertical green single	β16	1.962	-0.339	-0.252	0.791	-0.494	0.820	2.520
Vl1	Vertical green 1 side	β17	-2.955	0.338	-0.576	**2.908**	-5.138	-1.142	1.584
Vl2	Vertical green 2 sides	β18	0.169	0.032	0.001	**-0.529**	**-0.389**	0.016	0.044
Effects with significance levels < .05 are marked in bold.									

Age

Age shows some significant differences in the means, especially for the age group 41-60 in relation to trees. The effects are positive, suggesting that, this age group, on average, attributes more restorative value to trees than the younger and older age groups. One patch of hedge is also attributed a higher restorative value by this medium age group.

Education

Results indicate several significant differences between education levels, suggesting that in general, the lower the education level, the lower the attributed restorative value, most specifically for trees and higher intensity greenscapes. The large and positive value for vertical green along one side of the street for people with a low education level stands out.

Income

Significant differences in mean restorative values are found for several attributes, most consistently for trees. The higher income group shows higher values for almost all tree subtypes, while the lower income group seems to derive higher values from large trees only.

Grass along both sides of the street have higher restorative values for both lower and higher income groups, while hedges along both sides of the street have a higher restorative value for only the high income group. Note that the dummy coding for the income categories used the respondents not wishing to disclose their income level as the base. This aimed at finding explicit values for both low and high income groups.

5.3 Restoration likelihood

In order to measure the restoration likelihood of street profiles and the contribution of constituent greenscape elements and configurations, respondents were asked to rate street profiles on five items related to restoration likelihood. Each respondent rated the same eight profiles they were offered to choose from in the choice experiment. The setting was also the same: walking home when in need of restoration. Respondents were shown the eight profiles in random order and each time, the profile was shown in the center of the screen. Respondents could in addition click on the picture to start an 11-second video clip which showed a 'walk through' the virtual and fictional street environment. Respondents rated the scene on the five items, each on a 5-point Likert scale, ranging from strongly agree (5) to strongly disagree (1). The item ratings were analyzed using multiple linear regression.

5.3.1 Data check and preparation

The 4,956 respondents together rated 39,648 street profiles. Respondents saw the profiles before in the choice task, potentially inducing halo effects. However, the choice task and rating task were clearly distinguished as separate tasks, limiting such effects. The profiles were rated on 5 items for which item consistency was very high (Cronbach's Alpha of 0.954). Because each respondent viewed and rated eight profiles consecutively, item consistency was also calculated separately for all first, second, and up to eighth profiles shown. Cronbach's Alpha ranged from 0.933 (for all first profiles), to 0.945 (2nd), 0.954 (3rd), 0.956 (4th), 0.960 (5th), 0.959 (6th), 0.961 (7th) and 0.960 (8th). Furthermore, correlations between the ratings on the five items were very high (Table 5.5). The RL-items were intended as separate and different qualities related to restorativeness by Lindal & Hartig (2015). High item consistency and high correlations between the items, however, indicate the items are not independent. This argues for approaching the items as measuring a unidimensional construct. Such a unidimensional measure is one of the aims of this thesis: to find a quantifiable restorative quality of an environment and its constituent elements and configurations. Factor analysis (principal axis factor extraction) was applied to create a factor score for the five items, resulting in a single factor, accounting for 80.9% of the variance.

Table 5.5 Pearson correlation between items of RL-items

	Liking	Lkelhd of Rest.	Brk. Routine	Being Away	Fascination
Liking	1	.829[*]	.777[*]	.748[*]	.732[*]
Likelihood of Restoration	.829*	1	.866[*]	.851[*]	.780[*]
Break from routine	.777*	.866[*]	1	.878[*]	.800[*]
Being away	.748[*]	.851[*]	.878[*]	1	.817[*]
Fascination	.732[*]	.780[*]	.800[*]	.817[*]	1
* Significant at $p < .01$ n=39,648					

5.3.2 Analyses

Regression analysis was used to express the relationship between the factor scores and the dummy coded variables of the urban greenscape profiles, as well as gender, age (in age groups), education level groups and income groups. The regression was performed using NLOGIT6 (Econometric Software Inc., 2016) taking panel effects into account. The results are presented in Table 5.6 and shown graphically in Figure 5.4. The regression analysis allowed all possible interactions in the greenscape design, and interactions and socio-demographics were included through stepwise regression (threshold at .05).

Table 5.6 Parameter estimates using regression on the factor scores for the RL-data

		Parameter	Value	St. err.	Significance
Main effects					
C	Constant		-1.167	0.022	0.000
Tsc	Small tree single	β1	0.277	0.012	0.000
Tsl1	Small trees 1 side	β2	0.740	0.012	0.000
Tsl2	Small trees 2 sides	β3	1.126	0.012	0.000
Tlc	Large tree single	β4	0.417	0.012	0.000
Tll1	Large trees 1 side	β5	1.075	0.012	0.000
Tll2	Large trees 2 sides	β6	1.682	0.017	0.000
Gc	Grass single patch	β7	0.034	0.014	0.014
Gl1	Grass 1 side	β8	0.113	0.014	0.000
Gl2	Grass 2 sides	β9	0.258	0.014	0.000
Fc	Flowers single patch	β10	0.142	0.017	0.000
Fl1	Flowers 1 side	β11	0.356	0.015	0.000
Fl2	Flowers 2 sides	β12	0.756	0.016	0.000
Hc	Hedges single patch	β13	0.141	0.014	0.000
Hl1	Hedges 1 side	β14	0.374	0.015	0.000
Hl2	Hedges 2 sides	β15	0.727	0.017	0.000
Vc	Vertical green single	β16	0.030	0.010	0.002
Vl1	Vertical green 1 side	β17	0.061	0.009	0.000
Vl2	Vertical green 2 sides	β18	0.235	0.010	0.000

First order interaction effects					
Tsl2 x Hl2	Small trees 2 sides AND Hedges 2 sides	β51	**-0.131**	**0.029**	**0.000**
Tll1 x Hl1	Large trees 1 side AND Hedges 1 side	β74	**-0.108**	**0.030**	**0.000**
Tll2 x Fl1	Large trees 2 sides AND Flowers 1 side	β83	**-0.169**	**0.031**	**0.000**
Tll2 x Fl2	Large trees 2 sides AND Flowers 2 sides	β84	**-0.341**	**0.031**	**0.000**
Tll2 x Hl1	Large trees 2 sides AND Hedges 1 side	β86	**-0.167**	**0.032**	**0.000**
Tll2 x Hl2	Large trees 2 sides AND Hedges 2 sides	β87	**-0.416**	**0.031**	**0.000**
Tll2 x Vl2	Large trees 2 sides AND Vertical green 2 sides	β90	**-0.090**	**0.021**	**0.000**
Fc x Vc	Flowers single AND Vertical green single	β100	**0.073**	**0.026**	**0.006**
Fl2 x Vl2	Flowers 2 sides AND Vertical green 2 sides	β108	**-0.064**	**0.024**	**0.009**
Second order interaction effects					
Tsl1 x Hl1 x Vl1	Small trees 1 side AND Hedges 1 side AND Vertical green 1 side	β167	**-0.121**	**0.053**	**0.023**
Tlc x Gl2 x Vl1	Large trees single AND Grass 2 sides AND Vertical green 1 side	β206	**-0.142**	**0.053**	**0.007**
Tll1 x Fl1 x Vl1	Large trees 1 side AND Flowers 1 side AND Vertical green 1 side	β239	**-0.152**	**0.055**	**0.006**
Tll1 x Fl1 x Vl2	Large trees 1 side AND Flowers 1 side AND Vertical green 2 sides	β240	**-0.156**	**0.052**	**0.003**
Tll1 x Fl2 x Vc	Large trees 1 side AND Flowers 2 sides AND Vertical green single	β241	**-0.127**	**0.052**	**0.015**
Tll1 x Hl2 x Vc	Large trees 1 side AND Hedges 2 sides AND Vertical green single	β250	**-0.185**	**0.056**	**0.001**
Tll1 x Hl2 x Vl2	Large trees 1 side AND Hedges 2 sides AND Vertical green 2 sides	β252	**-0.173**	**0.051**	**0.001**
Tll2 x Gc x Vl1	Large tree 2 sides AND Grass single AND Vertical green 1 side	β254	**-0.148**	**0.052**	**0.004**
Tll2 x Gl1 x Vl2	Large tree 2 sides AND Grass AND Vertical green 2 sides	β258	**-0.145**	**0.056**	**0.010**
Tll2 x Gl2 x Vl1	Large tree 2 sides AND Grass AND Vertical green 1 side	β260	**-0.193**	**0.052**	**0.000**
Tll2 x Hc x Vc	Large tree 2 sides AND Hedges single AND Vertical green single	β271	**-0.146**	**0.054**	**0.007**
Socio-demographics					
Gender_F	Female (*male* is reference level)	βF	**-0.066**	**0.018**	**0.000**
Age_M	Age 40-60 (*61+* is reference level)	βAM	**-0.044**	**0.019**	**0.025**
Edu_L	Education level low (*high* is reference level)	βEL	**0.349**	**0.027**	**0.000**
Edu_M	Education level medium (*high* is reference level)	βEM	**0.182**	**0.021**	**0.000**
Effects with significance levels < .05 are marked in bold. $R^2_{adj} = 0.287$					

The analysis resulted in a model with a constant and 42 significant parameters (38 greenscape, 4 socio-demographic). In case a lower order effect is not significant, for instance the combination of small trees and flowers both along both sides of the street, the interaction of that combination with vertical green on 1 side, can be significant because of the value of this specific (dummy coded) combination.

In the regression model, negative parameter values are possible due to the use of a (normalized) factor score. The scores for the profiles ranged between -1.167 for the empty street, and 1.009 for the street with large trees, flowers and vertical green along both sides of the street.
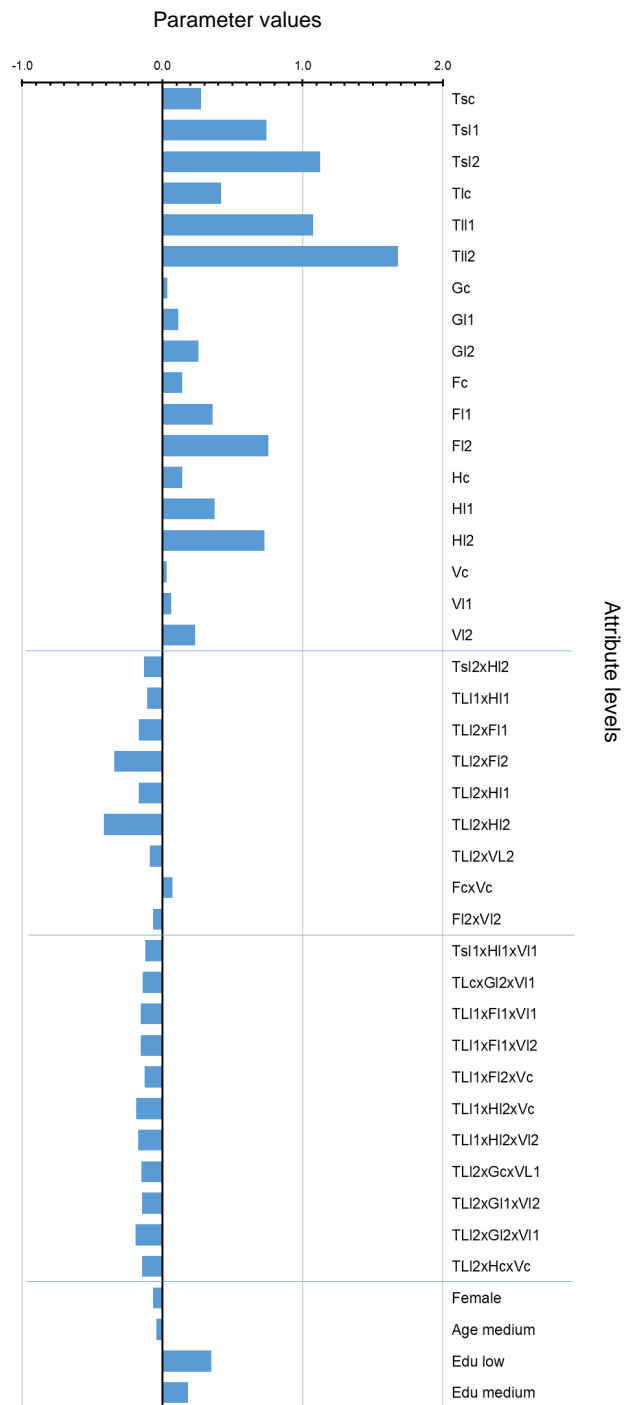
Figure 5.4 Graphic representation of the parameter values of the regression model

The model had an R^2_{adj} of .29. This R^2_{adj} value is quite modest compared to other studies using the restoration likelihood measures. Nordh et al.'s (2009) regression model on small park design, using ratings on an eleven point scale from a maximum of 14 convenience sampled respondents per statement, had an R^2_{adj} of .69. Lindal and Hartig's analyses (2015), concerning low to medium density urban residential streets with varied architectural and green design, using an eleven point scale and data from 188 respondents from an internet panel, representative of Iceland's population, had R^2_{adj} ranging between .42 and .61.

5.3.3 Main and interaction effects

The estimated contribution of greenscape elements and their configurations to the factor scores of restoration likelihood is represented by the corresponding parameter values. Main and interaction effects are described. Large trees have the highest effects, followed by small trees. Hedges and flowers have effects that are very similar in effect magnitude (medium), while grass and vertical green have the lowest effects. Most interactions are not significant; only 20 out of 261 greenscape interaction variables are significant. When significant, the interaction effects mostly are relatively small and negative: 19 out of 20 parameter values for interactions have a negative sign. The interaction effects for large trees and flowers on both sides (β84) and large trees and hedges on both sides (β87) have the largest (negative) values. The mostly negative values for the first order interaction effects suggest that combining (two) different elements has a marginally decreasing added restorative value. Combining additional green elements thus generally seems to lead to smaller increases in restorative value, unless some types and configurations with low main effects are combined.

Concerning the second order interactions, a more complex pattern seems to exist. As second order interactions always include vertical green, negative second order interaction effects actually exceed the low to very low main effects of vertical green in most instances, effectively reducing the total restoration likelihood value, i.e. more green leading to less restoration likelihood. For example, if you add vertical green on one side to a street with small trees and hedges on one side, the RL-value will decrease. This is unexpected for urban residential environments where greenery is rarely considered to be 'too much'. Similar to the discussion on the results of stated choice experiment, most studies find a positive restorative effect of increased greenery (e.g., Cox, Shanahan et al., 2017; Dzhambov et al., 2019).

5.3.4 Greenscape intensities

For the main effects, a further analysis was applied to the configuration by element type. The estimated restoration likelihood of greenscape elements and their configurations is visualized

by plotting the parameter values for each element (y-axis) against the different configurations (x-axis) (Figure. 5.5). The graph indicates that the main effects increase in relation to two factors: number of elements in the configuration and scale of the element. Effects increase when moving from configurations with few elements (left) to configurations with many elements (right).

Configurations with a single or concentric element (c) have a lower restoration likelihood value, while the linear configuration on one side of the street always has values between the c-configuration and the configuration linear on both sides of the street. It seems that the effect of the element is independent from the effect of the configuration.

Configurations →	c	l1	l2
— ▲ — Large trees	0.417	1.075	1.682
— △ — Small trees	0.277	0.740	1.126
— ■ — Hedges	0.141	0.374	0.727
— ▢ — Flowers	0.142	0.356	0.756
— ▨ — Grass	0.034	0.113	0.258
— ○ — Vertical green	0.030	0.061	0.235
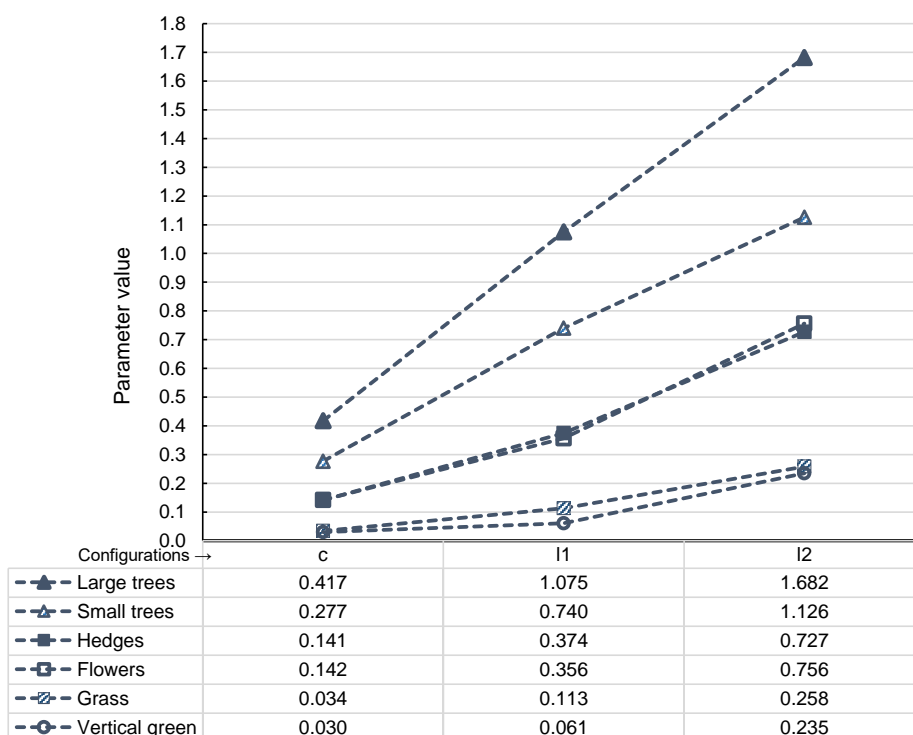
Figure 5.5 Parameter values for the main effects per element and configuration (regression model) (c = concentric or single; l1 = linear along one side of the street; l2 = linear along both sides of the street).

The concept of greenscape intensity derived from both the elements and the configuration, as previously defined, applies for the RL model as well: the elements with high impact, such as trees, have high element intensity, while elements with low impact, such as grass or vertical

green, have low element intensity. Configurations with multiple elements have high configuration intensity, while configurations with few elements or just one element have medium and low configuration intensity respectively. Using the concept of greenscape intensity, the estimated parameter values were plotted in 3D-space with value per configuration and per element (Figure 5.6). The plot shows that a higher intensity on either axis leads to higher parameter estimates (main effects only), and thereby a higher restoration likelihood value. Values on the different intensity dimensions seem to be able to balance each other. The single large tree (high element intensity and low configuration intensity) has an approximately equal parameter value as rows of flowers on one side (medium element intensity and medium configuration intensity) and rows of grass on two sides of the street (low element intensity and high configuration intensity).

A check was performed whether the model with the separate elements and configurations gave improved and more detailed insight to the restoration likelihood of an urban greenscape design. The model with the approach of only looking at the percentage of the picture representing natural elements plus the socio-demographic characteristics gender, age (in age groups), education level groups and income groups, has an R^2_{adj} of .255, which is lower than for the detailed model with R^2_{adj} of .287. This shows that distinguishing separate elements has added value over working with the overall greenscape impression when researching restoration likelihood.
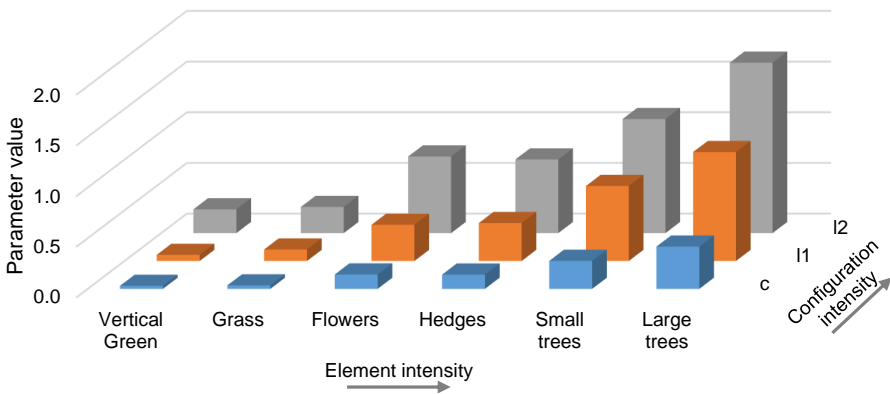
Figure 5.6 Greenscape intensities in two dimensions in relation to the main effects for restoration likelihood.

5.3.5 Influence of socio-demographic characteristics

The socio-demographic characteristics gender, age (in age groups), education level groups and income groups were included in the regression analysis. The very small negative value for the effect of gender indicates that women tend to rate the restoration likelihood slightly lower than men. Concerning age, the effect for respondents 40 years of age and below is not significant, while the effect for the age group 41-60 is very small and negative, compared to the age group 61 and older. Concerning education level, respondents with a high education were set as the benchmark. This makes the positive effects for medium and low education level indicate that the high education group rates the restoration likelihood lower, while respondents with a low education level rate the restoration likelihood of the urban greenscape profiles higher. The medium education level group is in between. Effects for the income variables were not significant, suggesting income does not significantly influence the restoration likelihood ratings. Over the four socio-demographic characteristics, Twedt et al. (2019) present similar findings in that age and education level had a significant effect on restorativeness.

To investigate whether certain socio-demographic characteristics also significantly interact with specific greenscape design attributes, an interaction term of the variables of the socio-demographic characteristics with the greenscape variables were added to the dataset as a block. An additional regression model was estimated (Table 5.7) using the variables for the main effects, plus the interaction variables for the main greenscape attributes with gender, age, education level, and income level.

Gender

Interactions with gender are significant for four effects. The significant effects are relatively small. For small trees, they are negative, indicating women attribute slightly less restoration likelihood to small trees. For flowers along both sides of the street, the effect is small and positive.

Age

The lower age group (40 years and younger) has two significant interaction effects, a small positive one for large trees along one side of the street, and a negative one for a single patch of flowers. The other effects are not significantly different than the reference 61+ age group. The medium age group (41-60 years) has three significant interaction effects: relatively small and negative values for small trees and hedges along both sides of the street, and for a single patch of flowers.

Table 5.7 Parameter estimates for interactions of socio-demographic characteristics with greenscape attributes (regression model)

Variable		Para-meter	Gender (*male* is ref. level) Female	Age (*61+* is reference level) 40 and below	41-60	Education level (*high* is reference level) Low	Medium	Income level (*no answer* is reference level) Low	High
Tsc	Small tree single	β1	**-0.049**	0.001	-0.025	**0.113**	0.017	0.039	0.010
Tsl1	Small trees 1 side	β2	**-0.045**	0.004	-0.020	**0.189**	0.013	**0.079**	0.025
Tsl2	Small trees 2 sides	β3	**-0.060**	0.009	**-0.074**	**0.177**	**0.054**	**0.073**	0.056
Tlc	Large tree single	β4	-0.026	0.054	0.017	0.049	0.032	0.035	0.035
Tll1	Large trees 1 side	β5	-0.011	**0.068**	0.029	**0.083**	0.027	0.044	**0.064**
Tll2	Large trees 2 sides	β6	-0.011	0.051	0.033	-0.041	-0.032	0.045	**0.089**
Gc	Grass single patch	β7	-0.016	0.009	-0.015	**0.093**	**0.123**	-0.005	-0.012
Gl1	Grass 1 side	β8	-0.044	-0.017	-0.026	**0.098**	**0.158**	0.029	-0.023
Gl2	Grass 2 sides	β9	-0.002	-0.030	-0.026	**0.131**	**0.157**	0.007	-0.057
Fc	Flowers single patch	β10	-0.030	**-0.120**	**-0.061**	**0.120**	**0.096**	0.032	-0.045
Fl1	Flowers 1 side	β11	0.032	-0.022	-0.021	**0.184**	**0.125**	0.030	**-0.090**
Fl2	Flowers 2 sides	β12	**0.070**	-0.062	-0.041	**0.274**	**0.184**	-0.013	**-0.111**
Hc	Hedges single patch	β13	-0.008	-0.024	-0.009	**0.115**	**0.091**	0.012	**-0.073**
Hl1	Hedges 1 side	β14	-0.007	-0.033	-0.043	**0.135**	**0.109**	0.027	-0.039
Hl2	Hedges 2 sides	β15	0.028	-0.058	**-0.107**	**0.281**	**0.156**	0.065	**-0.091**
Vc	Vertical green single	β16	0.009	0.011	-0.004	**0.073**	-0.032	-0.023	-0.024
Vl1	Vertical green 1 side	β17	0.008	-0.022	-0.007	**0.065**	0.008	0.015	-0.002
Vl2	Vertical green 2 sides	β18	0.007	-0.024	-0.034	**0.055**	0.021	0.042	0.032
Effects with significance levels < .05 are marked in bold.									

Education

Education level shows significant interactions for most effects. For the lower education level, only effects for a single large tree and large trees along both sides of the street are not significant. All other interactions indicate that respondents with a lower education level rate the urban greenscape elements and configurations higher than respondents with a high education level. The highest value is found for hedges along both sides of the street. Respondents with a medium education level notably seem to structurally rate horizontal green of any type and configuration higher than respondents with a high education level. For respondents with a medium education level, positive values are found for all horizontal green and for small trees along both sides of the street. Overall, it seems that respondents with low and medium education levels rate greenscape designs more positively than respondents with a high education level, and that respondents with low education level do so more strongly than those with medium education level. Some specific details on element and configuration level are present.

Income

Significant interactions are found for some effects. Respondents with a low income rate small trees along one side and both sides of the street as slightly more positive than the group that did not wish to disclose their income. Respondents with a high income rate large trees along one and both sides as slightly more positive. In addition, the high income respondents rate flowers and hedges along both sides, flowers along one side and one patch of hedges as slightly more negative than the group that did not wish to disclose their income. The lack of a clear pattern is possibly due to the 'no answer' option used as the base in the analysis as well as aggregation of income groups in only high and low income, dividing a middle income group into either high or low.

The results suggest there is limited heterogeneity due to the included socio-demographic characteristics in rating restoration likelihood. Interaction with education level showed most significant and the highest values, indicating this may be the most relevant socio-demographic characteristic in relation to rating restoration likelihood, while most research tends to focus on gender differences in relation to psychological restoration (e.g. Beil & Hanes, 2013). Results show that respondents with low and medium education level in general attribute more restoration likelihood to the main urban greenscape elements than respondents with a high education level.

5.4 Conclusions

The data gathered in the study was used to find the relationships between greenscape designs and restorative value on the one hand, and restoration likelihood on the other. Choice modeling and regression techniques were used to estimate models that best predicted the greenscape designs chosen and the ratings the designs were given, in relation to the dummy coded greenscape variables, indicating whether a certain greenscape element, configuration and interaction was present.

Regarding the analysis of the stated choice experiment, the estimated model showed the large restorative value that trees in general, and large trees specifically, have in the urban greenscape. Furthermore, flowers and hedges are considered to have medium restorative value, while grass and vertical green are considered to have low restorative value. Interaction effects, measuring the influence of combinations of green elements, were relatively small. Configurations with large, or many elements had more restorative value than those with small or few elements. This finding on elements and configurations led to the definition of the

concept of greenscape intensity as a measure of impact the urban green has on the total environment. Greenscape intensity is the sum of the similarly scaled, and thus to some extent interchangeable, element intensity and configuration intensity. However, the ML model taking separate elements and configurations into account has better model fit than when modeling with a more holistic variable for the urban greenscape as a whole (percentage of field of view covered by natural elements). Analyses including socio-demographic characteristics showed most notably significant effects for people of age 40-60, females and high income groups generally attributing more restorative value to trees, while respondents with a low or medium education level attributed less restorative value to trees. Regarding the other urban greenscape elements and configurations, some mostly positive influence is present of the socio-demographic characteristics for generally the higher intensity elements and configurations.

Regarding the analysis of the restoration likelihood task, item consistency and factor analysis of the data showed that the five items that the greenscape designs were rated on, can be joined into a single measure for analysis and presentation, and can then act as a unidimensional measure of restoration likelihood. The resulting factor score was used for regression analysis. The regression model showed a large restoration likelihood attributed to trees in general, and to large trees specifically. Flowers and hedges were attributed a medium value of restoration likelihood, while grass and vertical green were attributed a low value of restoration likelihood. Interaction effects were relatively small. Similar to the stated choice task, configurations with large or many elements provided more restoration likelihood than those with small or few elements. These results of the RL approach support the broader usability of the concept of greenscape intensity.

Regression modeling taking separate elements and configurations into account resulted in better model fit than when modeling with a more holistic variable for the urban greenscape as a whole (percentage of field of view covered by natural elements). Including the socio-demographic characteristics of gender, age, education level and income level, showed that education level had the largest influence on the restoration likelihood of the urban greenscape in general. The additional more detailed analysis of the influence of socio-demographic characteristics on specific elements and configurations showed that respondents with certain socio-demographic characteristics did in some cases attribute different restoration likelihood ratings to details in greenscape design. The clearest pattern was found for education: people with a lower and medium education level generally rate the greenscape elements and configurations higher on restoration likelihood, most specifically for all forms of horizontal green. For the other socio-demographic characteristics the results were small and diffuse.

Most importantly, the analysis not only established that different greenscape elements and designs are clearly distinguishable and quantifiable in their separate contributions to greenscape restorative value and restoration likelihood, but also that those separate influences lead to better predictions on restorative value and restoration likelihood of greenscape designs.

Chapter 6

Discussion and conclusions

6.1 Introduction

In a rapidly urbanizing world, city dwellers increasingly need to cope with stressful urban environments, resulting in an increased need for opportunities to relax and escape from daily hassles. Natural environments are very efficient in offering opportunities for such psychological restoration. Cities, however, have limited space for a broad selection of functions, of which nature is only one. Rather than only planning large surface areas of nature in cities, such as parks, one could also consider small scale natural elements that may be found in ordinary residential streets as a space-efficient and effective form of urban green. Additional green in this urban greenscape can lead to an increase in restorative effects through the potential high frequency with which citizens encounter natural elements in their daily urban life, providing possibly small, yet many restorative effects.

There is, however, very limited knowledge on these restorative effects of the urban greenscape. Therefore, this PhD study was conducted to examine the restorative value of urban greenscape designs using a choice experiment based on 280 different greenscape designs that vary combinations of elements and configurations in a virtual environment. Furthermore, restoration likelihood of the same greenscape designs was measured. The data were collected among nearly 5,000 citizens of four cities in the South of the Netherlands. In this concluding chapter, the main conclusions regarding the research questions are drawn. Implications for the planning and design of urban green are discussed, and some recommendations for future research directions are made.

6.2 Restorative value of the urban greenscape

This research project aimed to establish the nature and strength of the relationship between different green elements and configurations of the urban greenscape and restorative value as main research objective. In order to do so, it addressed four research questions. The first research question was: *How to best measure the restorative value of an environment and its constituent elements and configurations?* In an attempt to avoid some common issues in restorative environments research, such as regular use of convenience samples, small

sample size, and use of photographic images of real locations, a stated choice experiment using systematically varied greenscapes in a virtual fictional environment was executed with a large and broad sample. The adopted stated choice experiment asked respondents to choose from two alternatives the one that provides them the highest restorative value. A mixed logit model was estimated on the choice data. In addition, restoration likelihood, a regularly applied measure, was measured. Scores on restoration likelihood items measure a construct closely related to restorative value. A regression model was estimated on the restoration likelihood scores.

Having decided on the methodological approach, the second research question asked: *Are the presumably relatively small restorative values of elements and configurations in the urban greenscape discernable*? Results of the analyses showed that restorative values varied strongly between different elements and configurations. The more subtle green elements (especially grass and vertical green) and configurations (specifically the configuration with only a single element) had in some cases no significant main effect for restorative value, suggesting that those effects are not discernable, or not relevant. In contrast, the other elements (trees, flowers and hedges) and both linear configurations along the street had clear significant effects. Moreover, the regression model based on the restoration likelihood ratings had significant values for all main effects. From this finding, one can conclude that restorative values and restoration likelihood of separate elements and configurations in the urban greenscape are discernable for most elements and configurations, positively answering the research question, at least in this study for the current large sample.

Next, analysis considered whether discerning those separate effects also leads to more detailed knowledge, addressing the third research question: *Does taking separate elements and configurations into account lead to better predictions of restorative value than researching the urban greenscape as a whole?* The findings indicate that analyzing restorative values on the element and configuration level leads to more detailed knowledge and to better model fit compared to the model based on only the percentage green elements in the image. The more generic or holistic approach of elements and configurations, however, also provided an interesting insight, which led to the definition of greenscape intensity, consisting of element intensity and configuration intensity. These intensities were found to be interchangeable to some extent: a low element intensity (e.g., grass) can be 'compensated' by a high configuration intensity (e.g., along both sides of the street).

As the restorative value and restoration likelihood are based on two theories, last, the fourth research question was C*an Stress Recovery Theory (SRT) and Attention Restoration Theory*

(ART) be extended to the urban greenscape. The consistent results for both measures used in this study provide support for applying ART to the experience of nature in the urban greenscape. However, as the scenario and questions were framed primarily towards mental fatigue, rather than stress, this cannot as strongly be concluded for SRT.

Having answered these research questions allows returning to the main research question: *What is the nature and strength of the relationship between different green elements and configurations of the urban greenscape and restorative value?* Both applied methods indicate that among natural elements, the relative importance of trees is significantly higher than other features. The indications for this found by Lindal and Hartig (2015) were clearly confirmed. The importance of trees is true for all configurations and more strongly for large trees than small trees. The restorative value of horizontal green in the urban greenscape depends on the type of horizontal green. Flowers and hedges have about equal restorative value and these values are much higher than that of grass. Vertical green has a very low relative importance. The mechanics behind the very high restorative value of trees relative to the other urban green elements merits further and more specific research. This could be approached through exploring the influence of proportion of field of view and potential of a more integrated nature experience, due to trees providing more impact on view, sound and smell than smaller elements, possibly leading to an improved perception of so called ecosystem services. Ecosystem services are any benefit nature provides, i.e. besides the psychological benefits that are the focus of this research, benefits such as clean air, temperature regulation, and habitat for life (Gómez-Baggethun & Barton, 2013), and also social ecosystem services have been distinguished, focusing on 'non-material' benefits, such as experiences (Riechers, et al., 2018). Viewing trees, or other forms of nature may trigger a subconscious valuation of such ecosystem services, potentially increasing the intensity of the nature experience. Moreover, practical positive effects of such services provided by the presence of natural elements may be experienced adding to the perception of restorative value. For example, the potential for shade under trees offers a good strategy to deal with heat related issues in cities (I. Lee et al., 2018). In contrast, citizens can also experience practical negative effects of trees in residential streets, such as uneven pavement and nuisance from sap or sticky juice on cars (e.g., Lohr et al., 2004). Such additional positive and negative aspects were not part of the research, but could influence perceptions of restorative value.

Concerning the configurations, the results clearly show that configurations with more elements provide more restorative value, consistent with the literature (e.g., Cox, Shanahan et al., 2017). Moreover, the highest restorative value is found for natural elements along both sides of the street. Note that natural elements along the street, not only mean there is simply more

green, but through the linear design, could have a restorative value in itself. In contrast, Zhao et al., (2020) found no significant influence on perceived restorativeness of 'continuity of trees along streets', but their study explicitly included varied (linear) urban elements (such as fences and power lines) as well, which may have affected the relative impact of green elements. Further research could address to what extent the amount on the one hand, and the linearity on the other, provides the restorative value. This could be done by systematically varying greenscape configurations on both dimensions *amount* and *structuring*, including the now excluded combination of high amount and low structuring, to establish the respective contributions of both dimensions.

Even though there are indications in the literature that combining different greenscape elements may lead to significant interaction effects (e.g., Nordh et al., 2011), results in this thesis show that most interaction effects in this study are not significant. The interaction effects that are significant are relatively small and thus only marginally influence the total restorative value of the greenscape design. As the interaction effects are dummy coded, the estimated interaction effects represent the additional restorative value of combining two or three different elements, on top of the main effects, relative to the street devoid of green. For a large part, and specifically for attributes with higher intensities, interactions are negative, suggesting that the restorative value of a combination of the relevant attributes is less than the sum of their positive main effects, i.e., combining green elements leads to smaller increases in restorative value. Further research into a, from management and design perspective, optimum above which limited additional benefit can be achieved, is advised.

Differences in restorative value were found associated with some socio-demographic characteristics. For restorative value, the most relevant differences are that females and people aged 41-60 seem to generally attribute slightly more restorative value, specifically to trees. People with a high education level consider trees linear along the street to have a higher restorative value and people with a high income level consider trees in most configurations to be of higher restorative value. Regarding gender, there is an argument to make that gender differences in experience of urban nature are of importance (e.g. Roe et al., 2013) also in relation to perceptions of safety (e.g., Basu & Nagendra, 2021; Braçe et al., 2021). In recent years, the idea of more inclusive urban design (e.g., Odbert, 2022) has made the point that (among others) the female perspective deserves more attention in urban design, and the design of urban green is one of the areas of concern. Nevertheless, findings from this study suggest that women do appreciate trees in designs for restorative value, although the fact that in this research the female respondents also tended to be younger, means that it is difficult to be certain about whether it is predominantly gender, or age, that influences the results.

Similarly, the significance of trees to restorative value for the age group 41-60, can be confounded with gender. Otherwise, a suggested reason for the importance this age group puts on trees could be related to life stage effects, where for instance elderly possibly perceive more negative side effects of urban trees, such as fallen leaves, and protruding tree roots, resulting in slippery and uneven pavement (Lohr et al., 2004), posing higher risks of falling. Such perceptions may limit the impact of the otherwise beneficial psychological effects of trees. Considering education level, increase in education level is associated with increase in restorative value, specifically of trees. A possible explanation could be that people with a higher education level tend to live in more spacious neighborhoods, more commonly and easily accommodating (large) trees, without directly resulting in experienced negative side effects, while in less spacious neighborhoods, such negative side effects will sooner be experienced. All suggested reasons are hypotheses to be tested in further research.

For restoration likelihood, particularly for horizontal green, decrease in education levels is associated with an increase in restoration likelihood, most clearly for horizontal green. Possibly, citizens with lower education levels may experience more challenges in current day society, leading to more stressful daily life, as well as have smaller (or no) private green space in the form of a garden available, and hence more to gain from publicly provided nature experience close to home (for which indications are found in Ward Thompson et al., 2016).

The conclusion regarding socio-demographic characteristics is that the differences between subgroups are small and partly diffuse, in line with the findings of Twedt et al. (2019). There is reason to assume differences between subgroups, but research specifically aiming at these differences should be set up to establish with more certainty what those differences are.

Discussion of potential impact of operational decisions
The findings must be considered in light of operational decisions regarding the elements and configurations, and experimental design and measuring. Operational decisions regarding the virtual environments are discussed in the section on limitations.

Regarding the elements and configurations in the design of the experiment, small and large trees, and grass, flowers and hedges were levels within the variables trees and horizontal green respectively, implying that urban greenscape designs in the experiment did not include *combinations* of small and large trees, nor of grass, flowers and/or hedges. Similarly, no combinations of elements configured linearly on one side and singular on the other was included. Such combinations may also be of value, and merit future research.

Moreover, choices regarding qualitative aspects of the natural and built elements in the virtual environment may have impacted the results and should be considered in relation to real environments and influence of season or maintenance. For example, flowers are not always colorful and (deciduous) trees look bare in winter, which in relation to the concept of greenscape intensity, would mean that in winter they will have lower element intensity. In the research, a generic deciduous tree type was used, but research shows that tree type also influences affective responses (Lohr & Person-Mims, 2006). Moreover, visual evidence of a tree being badly maintained or dead, or uneven pavement due to tree roots could lead to negative attitudes towards natural elements present, and thereby diminish the restorative value of the urban greenscape. Different impacts of different qualitative aspects should be researched.

Next, potential impact of operational choices regarding experimental design and measuring are discussed. First, Respondents were presented a set of eight different profiles, out of a total of 280, to limit respondent burden. Some respondents may have been presented strongly differing profiles in the choice sets and rating task, while others may have been presented rather similar profiles. For the choice data, this is of little relevance, because a choice had to be made and the profiles always contained differences. The statistical modeling can therefore always distinguish what difference(s) led to the choice. However, for the rating task, very similar profiles risk getting rated *equally*, potentially leading to lower discriminating power. This risk increases because of the use of a shortened Likert scale, as imposed by the municipalities. This may have impacted the results, as well as the model fit of the regression model.

Second, measures of restorativeness rely on the assumption that respondents can sufficiently assess restorativeness. This research included two measures, of which stated choice experiments are specifically developed to assess a value respondents attribute to alternatives based on the underlying construct, which in this case was restorative value. This approach should mitigate the risk of respondents having difficulty to assess restorativeness. The very similar findings for both measures suggest that respondents are at least consistent in assessing restorative values and restoration likelihood across the two different measures, which may provide input for future research.

This research set out to establish the restorative value of separate green elements and their configurations in a street. Such a restorative value is considered a quality of the environment, which, when experienced, may lead to restoration in citizens. Restorative value, thus, is not the same as actual restoration. Restoration is a person-environment transaction, and is shown

to depend on many other factors besides the physical environment, such as the social environment (other people), activity, personal and sociodemographic characteristics, and need for restoration. Using the knowledge gained from this research can help in shaping environments to be supportive of restoration. Suggestions how to do so are discussed in the section on policy implications.

6.3 Limitations

A virtual environment was used to minimize influences other than the differences in the urban greenscape, aiming to allow finding subtle differences. Images of computer generated virtual environments proved to be effective in helping people make choices in hypothetical greenscape designs and the strict control exercised through these virtual environments led to high quality data, clear results and good model fit. For this kind of research and topic, where the object of study is a mostly visual cue, using virtual environments in combination with choice methodology can lead to significant results.

However, the use of very controlled virtual environments in which only the greenscape designs were systematically varied, has a potential downside in that effects may appear much larger than they would be in an environment that has more and other variation in its urban context. The example of the study by Zhao et al. (2020), as previously discussed, showed less strong findings on the role of configuration, possibly because of other linear but non-natural elements also varying. However, the possibly inflated results of the research can act as a good starting point for further research including also systematically varying urban elements.

Moreover, when working with visual cues, care must be taken when creating virtual environments, as the way the different green elements are visualized may play a role. For instance, in the virtual environment 'grass' is depicted in a shade of pale green without depth, which makes it not stand out as much as the colorful (red and yellow) 3D flowers or the high volume and dark green hedges. Moreover, for vertical green in the linear configurations along the street, wall-climbing plants were put irregularly on most, but not on all houses. Both choices may influence the results, potentially diminishing the measured restorative values of grass and vertical green as they were less prominently visible than the other urban greenscape elements, and less than they would in reality.

Furthermore, it is a critical assumption that the task and presented virtual environment trigger people to feel sufficiently immersed in the scenery and allows them to imagine its restorative

value. If this would imply sound and smell are left out while these also influence the restorative value, this would be a limitation. Further research could incorporate a multisensory nature experience, for instance by setting up an experiment in a real environment, or by inviting participants to a controlled lab environment where sound, smell and wind can be added to the experience of the virtual environment.

Moreover, new opportunities arise with the continuing advancement of technology. Virtual environments can be made into virtual reality and in recent years augmented reality has been used in research in urban environments (e.g., Y. Wang & Lin, 2023). This opens up relatively easy opportunities to do research in a real environment. The actual sounds in the environment can then be altered to be in line with the different virtual (green) designs incorporated in it through the use of technology. Further experimenting and methodological research into this emerging technology is recommended.

The use of municipal citizens' panels is an efficient way to reach a large group of respondents and generate a high response. There are, however, also drawbacks of working with municipal panels. Citizens panels tend not to be representative of the actual population. As indicated by the municipal panel managers, citizens with an immigration background are underrepresented in the panels and older, highly educated males tend to be overrepresented. Moreover, the requirement to stay within the municipal guidelines for the use of the citizen panels can be at variance with academic standards related to the measurement of complex concepts. Furthermore, working with panels of multiple municipalities means working with different guidelines. Constructing a single questionnaire that fits all guidelines may be very time-consuming. In this case, it took almost a year from the first contact to the invitation e-mail to panel members. In addition, panelists of citizens' panels, unlike other dedicated panels, are not used to academically driven surveys, but rather to (brief) questionnaires containing simple questions of a strong applied nature. This may adversely affect the validity and reliability of their responses.

By using the panels, the results are currently for respondents from the southern part of the Netherlands. It would be interesting to investigate to what extent cultural differences lead to different results. Future research should aim at differences between regions in the Netherlands, and between countries, preferably also non-Western. Furthermore, a recommendation is to specifically seek more respondents with immigrant backgrounds within Dutch society.

6.4 Policy implications

As restorative values and restoration likelihood of separate green elements and configurations are shown to be discernable, it follows that choices in street and greenscape design influence its restorative value and restoration likelihood simultaneously. The urban greenscape thus merits more space, budget and political attention and a more prominent role in urban planning.

On a more detailed level, this study confirms the importance of trees in residential streets, justifying more time, effort, budget and space to keep large trees healthy and present in residential streets. Designing urban areas should start with taking stock of the existing (large) trees and then design with them, instead of first removing them and then 'replanting' a smaller version. The possibility that the new tree will ever become as large is very small. Furthermore, dealing with any problems (large) trees may cause, should be done in ways other than removing them. Large trees are either currently present or should grow from small trees over a period of decades. If they do not have enough space in soil, sunlight and protection from detrimental urban influences such as cars bumping into them or inappropriate pruning, they will never grow to their full potential, nor stay healthy once large. Therefore, for both existing and new trees, from a design perspective, professionals should allow for more space for roots to grow, less pavement and more open soil, techniques to prevent soil being compacted too much, wider street profiles and increased distances to homes, especially on the shadow side. Such design with more room for specifically trees (as well as urban green in general) will result in a more open urban environment and it conforms with the idea that trees should have enough space for all their growth stages (Ruyten, 2006). This would mean less dense urbanization, or taller buildings and smaller homes allowing more homes per hectare, despite the increase in space for green. Additionally, novel ways to achieve higher density while also allowing more space for green, need to be explored.

Regarding the other types of elements in the urban greenscape, the knowledge that flowers and hedges have a much higher restorative value than grass may help local governments consider novel forms of urban greening, based on the different aspects of cost versus effect. Costs, typically associated with maintenance, favor grass, but by providing more space to allow flowers and plants to grow more spontaneous and wildly along the roads, less maintenance is required, while simultaneously valued natural elements are added to the urban greenscape. Besides horizontal green, vertical green seemed of little influence. However, from a practical point of view, as vertical green requires little space and is typically owned (both physically and psychologically) by citizens instead of the local government, it may be a cost and space efficient way to add urban green experience, even when effects are relatively small.

The finding that element intensity and configuration intensity are broadly interchangeable, implies that similar intensities can be achieved through different design choices. Where there is not enough space for high intensity elements like large trees (for instance because of an underground parking garage), or where trees are not large yet, urban designers can consider lower intensity elements in a higher configuration intensity to achieve a similar overall intensity. Furthermore, making designs with combinations of urban green elements is advisable as combinations generally lead to higher total restorative values, despite the mostly negative significant interaction effects as the interaction effects are relatively small compared to the main effects. When there is limited space for high intensity elements, nor for high intensity configurations, municipalities should strive to still plant at least a single tree accompanied by some other form of urban green element.

This thesis has focused on the role of the urban greenscape in making neighborhoods act as a restorative environment for citizens. It started from the premise that the neighborhood and residential street is the level where citizens are most likely to regularly encounter natural elements when going about their daily activities. In addition, urban green elements in the residential street may also provide an important function for readily accessible nature experience in case of a need for immediate stress release, and they can be experienced through window views onto the street, further strengthening the potential for regular restorative experiences. Last, the urban greenscape additionally offers societal benefits around heat, water and climate, and ecological benefits such as providing habitat functions, making conscientiously planning and designing the urban greenscape even more important.

6.5 Directions for future research

In addition to future research proposed in relation to the findings, limitations and policy implications above, some broader directions for future research are suggested.

Regarding the urban greenscape, this study chose to put limitations to the number of greenscape elements, configurations and combinations for research feasibility. A broader selection of greenscape elements, configurations and combinations should be examined in the future, allowing for seasonality, different climate zones and accompanying vegetation types, as well as cultural dimensions regarding those elements, configurations and combinations.

Moreover, although the urban greenscape is part of an urban environment, in this study, the urban context, including aspects such as building style, was not included. Future research should consider the restorative value of urban greenscape elements and configurations in different urban environments to establish the relative importance of greenscape design and urban context. Other aspects that merit further research regarding the relative importance of restorative value of the urban greenscape could include social context, distinguishing functional from leisure motives in daily activities in the neighborhood, and mode of transport while experiencing the urban greenscape.

Last, stress reduction in addition to attention restoration, can be explicitly measured through varying means, including physiological responses of the human body. By collecting and analyzing data related to SRT as well as ART, better understanding of the interrelationship between both theories may be achieved.

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Appendices

Appendix A: Selection of used images of different street profiles

Small trees, both sides of the street

Large trees, one side of the street

Grass, both sides of the street

Flowers, one side of the street

Hedges, one patch

Vertical green, both sides of the street

Small trees, hedges and vertical green, both sides of the street

Large trees, flowers and vertical green, both sides of the street

Overview of elements in their possible configurations

Grass   Flowers

Hedges   Vertical green

Note: for research purposes, all images and movie clips can be shared upon request.

Appendix B1: Questionnaire - Dutch

Dutch version for Eindhoven

Welkom bij deze vragenlijst naar groen in Brabantse steden. Dank u wel dat u mee wilt doen.

Om steden zo plezierig mogelijk te maken, is het belangrijk te weten hoe burgers verschillende soorten groen in de straat beleven. Dat is wat wij onderzoeken.

Deze vragenlijst gaat over **straatgroen**. Daarmee wordt al het openbaar groen bedoeld dat in een 'normale' woonstraat aanwezig kan zijn. U kunt daarbij denken aan bomen, grasstroken, bloemperken en muurplanten. Het gaat in dit onderzoek niet om voortuinen van mensen zelf.

Wat praktische zaken:
- Het invullen van de vragenlijst duurt ongeveer 15 minuten. Dit kan wat langer zijn dan u van de gemeente-onderzoeken gewend bent.
- Wij willen u vragen de vragenlijst helemaal en in 1 keer in te vullen. Dat maakt uw antwoorden goed te verwerken.
- Al uw antwoorden en gegevens worden anoniem verwerkt.
- Vragen en opmerkingen kunt u sturen naar r.p.dongen@tue.nl
- **Het kan zijn dat onderdelen van de vragenlijst nogal op elkaar lijken. Dat is dan juist de bedoeling.** We zijn ook op zoek naar die kleine verschillen. Probeer daarom de vragen altijd zo nauwkeurig mogelijk te beantwoorden.

Deel 1: Achtergrond, groen in Eindhoven

Allereerst een paar algemene vragen over het straatgroen in Eindhoven.

Wat vindt u in het algemeen van het straatgroen in Eindhoven?

1. Van straatgroen is er in Eindhoven:

[-2] Veel te weinig

[-1] Iets te weinig

[0] Precies genoeg

[1] Iets te veel

[2] Veel te veel

2. Het straatgroen in Eindhoven is:

[2] Zeer afwisselend

[1] Afwisselend

[0] Niet afwisselend en ook niet eentonig

[-1] Eentonig

[-2] Zeer eentonig

3. Zijn er dingen die u aan het straatgroen in uw wijk verbeterd wilt zien?

[0] Nee, ga door met de volgende vraag.

[1] Zo ja, welke verbeteringen zijn dat? (Maximaal twee antwoorden in steekwoorden)

    [verbeteringen]

Page 3

Deel 2: Keuzes

U krijgt zometeen 7 keer een scherm met twee verschillend ingerichte straten naast elkaar te zien. Stelt u zich daarbij steeds het volgende voor:

- U heeft een drukke dag gehad.

- U bent te voet op weg naar huis.

- De twee straten die u te zien krijgt, zijn de 2 straten waar u op dat moment uit kunt kiezen.

- Het zijn beide logische routes en ze zijn even lang.

De vraag is: door welke straat loopt u het liefst naar huis?

Page 4-10   [7x:]

U bent na een drukke dag te voet op weg naar huis.

Welke straat kiest u om doorheen te lopen?

(De straten zijn verder precies hetzelfde, bijvoorbeeld in afstand.)

[0] A

[1] B

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Deel 3: Beoordelen

Er volgen nu 8 beelden van een woonstraat (eventueel ook als filmpjes te bekijken).

U wordt gevraagd de straat te beoordelen op een aantal stellingen.

Stelt u zich daarbij steeds het volgende voor:

- U heeft een drukke dag gehad.

- U bent te voet op weg naar huis door deze straat.

Page 12-19   [8x:]

U bent na een drukke dag te voet op weg naar huis door deze straat.

Bekijk het plaatje goed en stelt u zich voor dat u er echt bent.

U kunt op het plaatje klikken. Dan wordt het een kort filmpje van de straat.

Beoordeel de volgende stellingen:

- Ik vind dit een fijne omgeving

- Hier zou ik bij kunnen komen van mijn drukke dag; na een tijdje kan ik dan mijn aandacht er weer beter bij houden

- Hier zijn doorbreekt de dagelijkse routine

- Hier ben ik even weg van alles wat aandacht van me vraagt

- Deze omgeving fascineert me; mijn aandacht wordt getrokken door interessante dingen

[voor elk een 5-punts Likertschaal]

[1] Sterk oneens

[2] Oneens

[3] Neutraal

[4] Eens

[5] Sterk eens

Page 20

Deel 4: Uw achtergrond

Ter afronding volgen nu enkele vragen over uw achtergrond en over eventueel

vervolgonderzoek.

Met behulp van deze informatie kunnen we interessante verschillen vinden in antwoorden

tussen bepaalde groepen mensen, bijvoorbeeld tussen jongeren en ouderen.

Alle gegevens worden anoniem verwerkt en kunnen niet worden herleid naar een persoon of

adres.

Wat is uw leeftijd (in jaren)?

[Leeftijd in jaren]

Wat is uw geslacht?

[1] Man

[2] Vrouw

Wat is uw opleidingsniveau?

Kies uw hoogste afgeronde opleiding.

[1] Lager onderwijs / Basisschool

[2] LBO / LTS / VMBO

[3] MAVO / MULO

[4] HAVO

[5] VWO / Gymnasium

[6] MBO

[7] HBO

[8] Universiteit / Wetenschappelijk Onderwijs

[9] Post-academisch

[10]   Overig, namelijk: [andere optie]

Page 21

Vervolg: vragen over uw achtergrond

Kunt u een indicatie geven van uw persoonlijke (dus niet van het hele huishouden) bruto jaarinkomen? Kies 'Geen antwoord' als u deze gegevens liever niet geeft.

[1] Minimum (tot ongeveer € 15.000)

[2] Tussen minimum en modaal (van € 15.000 tot ongeveer € 30.000)

[3] Tussen modaal en 2 keer modaal (van € 30.000 tot ongeveer € 60.000)

[4] Meer dan 2 keer modaal (meer dan € 60.000)

[5] Geen antwoord

Tot welke nationaliteit rekent u zichzelf?

[1] Nederlands

[2] Turks

[3] Marokkaans

[4] Surinaams

[5] Anders, namelijk: [andere optie]

Hoe is uw huishouden samengesteld?

[1] Alleenstaand, zonder (inwonende) kinderen

[2] Alleenstaand, met (deels) inwonende kinderen

[3] Gehuwd of samenwonend, zonder (inwonende) kinderen

[4] Gehuwd of samenwonend, met (deels) inwonende kinderen

[5] Anders, namelijk: [andere optie]

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Deel 5: Vervolgonderzoek?

Naast uw mening over verschillende vormen van straatgroen, kan ook uw lichamelijke reactie gemeten worden, bijvoorbeeld aan de hand van uw hartslag.
Bent u bereid om aanvullend op deze vragenlijst in de eerste maanden van 2015 een keer naar een locatie in uw stad te komen om daar uw lichamelijke reactie te laten meten op verschillende vormen van groen in de straat? Dat onderzoek duurt zo'n 45 minuten. Wij zouden dat zeer waarderen en bieden u voor dat vervolgonderzoek op locatie een VVV-bon twv € 15 aan als bedankje.

Wilt u meedoen aan het vervolgonderzoek?

NB: dit vervolgonderzoek staat los van uw reguliere deelname aan het burgerpanel /
digipanel.

[0] Nee

[1] Ja, vul dan hieronder uw mailadres in. Wij zullen te zijner tijd contact met u opnemen om
    een afspraak te maken.   [mailadres]

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U bent nu aan het eind van deze vragenlijst. Door op 'Afronden' te klikken wordt de
vragenlijst afgesloten. Mede namens de vier deelnemende gemeenten, hartelijk dank voor
het meedoen aan dit onderzoek.

Zijn er nog dingen die u kwijt wilt over deze vragenlijst, of over het onderzoek?
[open opmerkingen]

Hartelijk dank voor uw tijd!
ir. R.P. van Dongen
r.p.dongen@tue.nl

Page 24

Hartelijk dank voor uw deelname.
U kunt nu uw internetbrowser sluiten.

Appendix B2: Questionnaire - English translation

English translation of version for Eindhoven

Please note:

- The questionnaire was executed in Dutch. In case of differences in meaning the Dutch version is leading, as this was the version that was used.
- For the question about education level (on page 20 of the questionnaire), the original specifically Dutch education system is changed to fit an international system for better understanding, reducing the number of answer categories.

Page 1

Welcome to this survey on Urban Green in the cities in Brabant. Thank you for participating!

To build cities that are as pleasant as possible, it is important to know how citizens experience different sorts, shapes and sizes of urban green. That is what we research.

This survey is about **the Urban Greenscape**: all the public natural elements that may be present in 'normal' residential streets. You could think of trees, grass strips, flowers and wall climbing plants. This research is not about private gardens or parks.

Some practicalities:

- Completing the survey should take about 15 minutes, which may be a bit longer than you are used with the municipal surveys.
- Would you please complete the survey fully and in one go? That makes the analysis of your answers easier and of higher quality.
- All your answers and data remain anonymous.
- Any questions or remarks you have, may be sent to r.p.dongen@tue.nl
- **It is possible that parts of the survey seem very similar. If that is the case, it is intended to be that way.** We are also looking for small differences, so please always try to answer the question as precise as possible.

Page 2

Part 1: Background, urban green in Eindhoven

First some general questions about urban green in Eindhoven.

What is your general opinion about public green in the streets of Eindhoven?

1. In Eindhoven we have:
[-2] Far too little urban green
[-1] Too little urban green
[0] Just about the right amount of urban green
[1] Too much urban green
[2] Far too much urban green

2. Urban green in Eindhoven is:
[2] Very diverse
[1] Diverse
[0] Neither diverse, nor monotonic
[-1] Monotonic
[-2] Very monotonic

3. Could you name one or two things you would like to improve regarding urban green in your neighborhood?
[0] No; please continue to the next question.
[1] If yes, what improvements would that be? (Maximum of two improvements) [improvements]

Page 3

Part 2: Choices

In the next pages you will see seven screens with each two streets differing only in green design. Please imagine the following:

- You have had a busy day.
- You are walking home.
- The two streets you see are the two options you have

- Both are logical routes home and they are identical in distance to walk.

They question is: along which street would you prefer to walk home?

Page 4-10   [7x:]

After a busy day you are walking home.

Which street do you choose to walk along?
(Other than the design, the streets are the same (for instance in distance)).

[0] A
[1] B

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Part 3: Rating

You will now get to see an image of a residential street 8 times (which may also be viewed as a movie clip). Please rate the street on the given statements.

Please imagine the following:

- You have had a busy day.
- You are walking home along this street.

Page 12-19   [8x:]

After a busy day you are walking home along this street.

Please take a moment to view the picture and imagine actually being there.
You may click on the picture to start a short movieclip 'walking' along the street.

Please rate the following statements:

- "I like this environment"
- "I would be able to rest and recover my ability to focus in this environment"
- "Spending time here gives me a break from my day-to-day routine"

- "It is a place to get away from the things that usually demand my attention"
- "This place is fascinating; My attention is drawn to many interesting things"

[For each a 5-point Likert scale:]

[1] strongly disagree

[2] disagree

[3] neutral

[4] agree

[5] Strongly agree

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Part 4: Your background

To finalize this survey: some questions regarding your background and an option for participation in further research regarding urban green.

With this information we can find interesting differences between groups of people, for instance between young and old.

All information is anonymous. Answers cannot lead to a person or address.

What is your age (in years)?

[Age in years]

What is your gender?

[1] Male

[2] Female

What is your education level?

Please choose the highest finished education level / degree.

[1] Primary school

[2] Secondary school

[3] Associate degree or certificate

[4] Bachelor

[5] Master

[6] PhD or advanced professional degree

[10] Other: [other option]

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Continued: questions about your background

Please give an indication of your personal (not household) yearly income before taxes. Choose 'no answer' if you would rather not share such information.

[1] Minimum (up to about € 15.000)

[2] Between minimum and modal (from € 15.000 to about € 30.000)

[3] Between modal and twice modal (from € 30.000 to about € 60.000)

[4] More than twice modal (more than € 60.000)

[5] No answer

What nationality do you consider yourself to have?

[1] Dutch

[2] Turkish

[3] Moroccan

[4] Surinam

[5] Other: [other option]

How would you describe your household?

[1] Single, without children living at home

[2] Single, with children living (partly) at home

[3] Married or living together, without children living at home

[4] Maried or living together, with children living (partly) at home

[5] Other: [other option]

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Part 5: Further research?

Besides your opinion on different urban greenscape designs, your physical reaction can also be measured, for instance by looking at your heart rate.

Would you be willing to come to a location in your city some time in the first months of 2015 to have your physical reactions to different greenscapes measured? That research would take about 45 minutes. We would greatly appreciate that and would like to offer you a gift voucher of € 15 for that further research.

Would you like to join further research?

Please note: this further research is not connected to your regular participation in the municipal citizen panel.

[0] No

[1] Yes; please enter your mail address below. We will contact you to make an appointment.
[mail address]

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You have reached the end of the survey. You may click 'Finish' to close the survey.

Also on behalf of the participating municipalities, thank you very much for participating in this research.

Is there anything you would like to let us know about this survey, or the research we are conducting?

[open comments]

Thank you for your time!

R.P. (Robert) van Dongen, MSc.

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Thank you for your participation in this survey.

You may now close your internet browser.

Curriculum vitae

Robert van Dongen was born on 15 April 1976 in Eindhoven, the Netherlands. After finishing Gymnasium in 1994 at Stedelijk Gymnasium in Nijmegen, the Netherlands, he studied Architecture, Urbanism and Building Sciences at Eindhoven University of Technology in Eindhoven, the Netherlands. In 2002 he graduated within the urbanistics group on the topic of competition between cities in Europe. Between 2001 and 2007 he worked for the government of the Eindhoven Region (SRE) most specifically on housing and nature development. In 2007 he made the switch to education at Breda University of Applied Sciences (then NHTV), teaching on his expertise and passion for (urban) nature, environmental psychology and the role of government in the built environment. In 2015 he joined the core team to develop a new international bachelor track on international spatial development. From 2013 he started a PhD project at Eindhoven University of Technology at Eindhoven, the Netherlands, of which the results are presented in this dissertation. Since 2019, he also works as a lecturer at Eindhoven University of Technology, active in education, and development of education, on all levels in urban planning & design. Robert is currently coordinator of the convening team of the Restorative Environments Network, bringing together researchers from across the world to exchange ideas and collaborate on researching restorative environments.

List of publications

Articles:

- Van Dongen, R. P. and H. J. P. Timmermans (2019). "Preference for different urban greenscape designs: A choice experiment using virtual environments." *Urban Forestry & Urban Greening, 44*, 126435. https://doi.org/10.1016/j.ufug.2019.126435

- Sezavar, N., Pazhouhanfar, M., Van Dongen, R. P. and Grahn, P. (2023). "Importance of designing the spatial distribution and density of vegetation in urban parks for increased experience of safety." *Journal of Cleaner Production*, 136768. https://doi.org/10.1016/j.jclepro.2023.136768

Published conference papers:

- Van der Waerden, P. J. H. J., Willems, R. & van Dongen, R. P. (2018). "Voorkeuren van fietsers met betrekking tot de hoogte en plaatsing van bomen langs fietsinfrastructuur in het stedelijke gebied", Published conference paper CVS, 2018, p. 1-13. 13 p.

Conferences:

- International Conference on Environmental Psychology (ICEP), Syracusa (It), 5-8 Oct 2021
  Organization of 2 symposia on restorative environments

- International Conference on Environmental Psychology (ICEP), Plymouth (UK), 3-6 (5) Sept, 2019. Presentation at conference: "Finding Restorativeness in Urban Greenscapes using Google Maps & Google Streetview"

- Transportation Research Board (TRB), Washington DC (USA), 8 Jan 2017. Presentation at invited workshop Visualization in SP surveys: "Visualizations and virtual reality in choice behavior research in spatial planning and urban design"

- Biannual Conference Environmental Psychology (BCEP), Groningen (NL), 24 Aug 2015. Presentation at conference: "Optimizing urban green design for restorative effects in residential streets"

Reeds verschenen in de serie
Bouwstenen

Nature in cities has many important functions for human well-being. Among others, it provides opportunities to relax and escape from daily hassles, through recovery from stress and restoration of capacities to focus attention. Through these psychological effects, nature can support an urban environment to be a restorative environment. Next to a sizeable volume of research on large scale green spaces, such as forests, mountains, and large urban parks, very few studies however, have been concerned with the urban greenscape: small scale nature in urban streets, such as grass verges, hedges or street trees. City dwellers encounter these natural elements on a regular basis, also when they may not actively seek them. Consequently, the urban greenscape may have a high potential to provide restorative effects to citizens.

Using municipal citizen panels in the four largest cities in the Dutch province of Noord Brabant, a sample of 4,956 respondents completed a stated choice task measuring the restorative value of virtual and hypothetical urban green profiles, and a rating task measuring restoration likelihood of the same profiles. The main findings indicate very large restorative value and restoration likelihood of trees in general and large trees specifically, and a relatively low restorative value and restoration likelihood of grass and vertical green. Additionally, the results lead to the definition of greenscape intensity, consisting of element intensity, related to the scale of the natural elements, and configuration intensity, related to the number or amount of natural elements. These intensities are interchangeable to some extent.

The findings of this study can be used as guidelines to better equip urban planning and design professionals to optimize the design of the urban greenscape at the detailed level of the urban greenscape, to maximize the restorative effects of nature in cities.

DEPARTMENT OF THE BUILT ENVIRONMENT

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