Chapter 1

General Introduction
For the vast majority of human history, humans have lived in natural environments as hunters and gatherers. Today, however, the world's human population mainly lives in urban areas. In Europe, already 73% of the current population lives in urban areas. This percentage will increase to over 80% by 2050 (United Nations, 2014). Rapid urbanization is accompanied by expansion of residential areas, for example in the United States where urban sprawl has led to an increase in built environment. In Western-Europe, ongoing urbanization has resulted in densification of cities through compact urban design (Fuller and Gaston, 2009). Although urban living has several socio-economic advantages, the global shift to highly urbanized populations has raised concern from scientists and policy makers, because of its possible negative impacts on health and well-being, especially in socio-economically deprived populations (Barton, 2009; Dye, 2008). For example, urban living is found to be associated with a more sedentary life style, leading to a higher risk of overweight and lifestyle-related chronic diseases such as diabetes type II and cardiovascular diseases (McMichael, 2000). Furthermore, several studies have found that urban living can have a negative impact on mental health (Evans, 2003; Lederbogen et al., 2011; Peen et al., 2010). The WHO has designated mental health as a public health priority, because almost a third of the population in Europe will experience mental health problems at some point in life (World Health Organisation, 2013). Therefore, maintaining and creating healthy cities, which offer “a physical and built environment that encourages, enables and supports health, recreation and well-being […]” (World Health Organization, 2012) is supposedly of great importance.

Of special concern is that urban densification may pose a threat to urban green spaces. Urban green space is commonly defined as open space between buildings that contains natural elements or vegetation such as parks, residential gardens, playgrounds and recreation areas (Kabisch and Haase, 2013; Swanwick et al., 2003). Due to the ongoing infill development of open spaces, urban private and public green space is under pressure, especially in rapidly expanding cities in Asia, and to a lesser degree in Europe and North America (Haaland and van den Bosch, 2015). In Europe, loss of urban green space has been documented for cities in the United Kingdom and in Eastern-Europe (Haaland and van den Bosch, 2015). For cities in Western-Europe an increase of urban green space was found between 2000 to 2006 (Kabisch and Haase, 2013). However, low green space availability per capita was found in compact cities with high population density (Fuller and Gaston, 2009). Moreover, the provision of urban green space is unevenly distributed over cities, with low availability of green space in socio-economically deprived neighbourhoods (Haaland and van den Bosch, 2015).

In the past two decades, there is a growing body of research that has investigated whether green spaces can be qualified as restorative environments or retreats from urban stressors. Green spaces, such as parks and forests, can provide attractive settings for physical and social activities and opportunities for experiencing nature. These experiences and activities may
contribute to the health of urban residents in all its aspects, where health is broadly conceptualized by the World Health Organization (2001) as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. When urban green space becomes scarce, urban citizens will have fewer opportunities for visiting such spaces and experiencing nature and, therefore, may not take advantage of the potential health benefits of green spaces.

PREVIOUS RESEARCH ON HEALTH BENEFITS OF GREEN SPACES

The belief that green space is an important for restorative experiences is longstanding (Olmsted, 1870; van den Berg and van den Berg, 2002). Scientific research on health benefits of green spaces, and, more specifically, of urban green spaces started to grow in the 80-ies of the last century and has become booming in the past decade. Much research in the field of the physical environment and health has traditionally focused on the negative health impacts of, for example, noise, air pollution, crime and crowding (Evans, 2003). In the field of public health research, there is growing interest in the physical environment as a determinant of healthy behaviour, e.g. physical activity (Brug et al., 2006). Nevertheless, few studies in the field of environment and public health have recognized that green spaces can be especially important for enhancing the health of urban residents in many ways. Green urban space might provide attractive places for leisure activities where urban residents find relief from the demands of modern life and urban stressors, such as noise and crowding (Evans, 2003; Frumkin, 2003; Kabisch et al., 2015), but, they may also play a role because of the restorative potential of being in contact with the natural environment as such (van den Berg et al., 2007).

Experimental research on green spaces as restorative environments

In 1993, the biologist Wilson hypothesized that all human beings have an innate affinity with nature (Kellert and Wilson, 1995; Wilson, 1984). This “biophilia”-hypothesis inspired environmental psychologists to develop theories on the restorative effects of contact with nature. These theories draw on this evolutionary perspective and emphasize the role of an unconscious, innate psycho-psychophysiological response: the attention restoration theory (ART) (Kaplan and Kaplan, 1989; Kaplan, 1995 ) and the stress reduction theory (SRT) (Ulrich, 1981; Ulrich et al., 1991; Ulrich, 1986). The attention restoration theory hypothesize that restoration is evoked by components of the environment that promote the sense of “being away” (from daily settings), draw effortless attention (or soft fascination), and facilitate “compatibility”, referring to the individual needs and characteristics of the environment being in harmony (Kaplan and Kaplan, 1989).
Where ART focuses on changes in attention, thus proposing a cognitive process as the primary mechanism at work, SRT focuses on changes in emotional state and stress arousal. According to the SRT, viewing green spaces with features that signal safety and possibilities for survival (such as moderate depth and complexity, presence of vegetation and water) leads to an immediate positive affective response, that reduces negative thoughts and states of autonomic arousal (Parsons, 1991; Ulrich, 1981; Ulrich, 1983; Ulrich et al., 1993). Both theories hypothesize that green environments contain more restorative components than built environments and, therefore, green environments (or spaces) have greater restorative potential.

Many laboratory and field studies have shown that contact with real green environments, and even with pictures or videos of green environments, as opposed to urban environments has positive effects on mood, self-esteem and self-reported feelings of stress and depression, and suggest that contact with nature can help to recover from stress and mental fatigue (see reviews e.g. Bowler et al., 2010; Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, 2004; Thompson Coon et al., 2011). However, fewer have investigated psychophysiological effects of exposure to green environments, compared with exposure to urban environments (Brown et al., 2013; Gladwell et al., 2012; Laumann et al., 2003; Li et al., 2011; Park et al., 2010; Pretty et al., 2005; Tsunetsugu et al., 2007; Ulrich, 1981; Ulrich et al., 1991). These experiments have provided support for the hypothesized restorative effects of short-term exposure to nature and have inspired the first large-scale epidemiological studies. Only a few studies have shown that exposure to green environments, as opposed to built ones, also may increase stress resilience by buffering the psychophysiological response to a future stressor (Parsons et al., 1998; van den Berg et al., 2010). Additional studies are needed that unravel underlying psychophysiological mechanisms and to clarify the role of (parasympathetic and sympathetic parts of) the autonomic nervous system in the stress responses.

**Epidemiological research on health benefits of green spaces**

In 2004, the Health Council of the Netherlands was one of the first that extensively reviewed the scientific evidence for a relationship between green space and health (Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, 2004). At that time, there were only two epidemiological studies that had investigated the relationship between long-term exposure to green space and health in large populations. The first, a Dutch cross-sectional study, found that a higher percentage of green space in a buffer around their home was associated with better general and mental health and fewer health complaints (de Vries et al., 2003). The data on self-reported health in this study were collected from a random sample of more than 10,000 people registered at general practices and were linked to land-use data on the availability of green space in the residential environment. The analyses were adjusted for several socio-economic and demographic confounders that could have obscured the associations. The second, Japanese, study investigated the five year survival rate of a cohort...
of more than 3000 seniors living in a highly urbanized area of Tokyo. They found that older people who perceived their neighbourhood as greener and easier to walk in lived longer (13% higher odds for survival), independent of age, gender, socio-economic status or other potential confounders (Takano et al., 2002).

In the past 15 years, the number of large-scale epidemiological studies that have investigated the possible health benefits of green space has increased sharply. Most studies were cross-sectional and have used Geographical Information Systems (GIS) to link data on green space to existing (secondary) health data. Many studies have replicated the study of de Vries et al. (2003), using different measures of the availability of green space in the surrounding residential environment and used self-administered scales to assess perceived general health and mental health as outcome measures (Maas et al., 2006; Maas et al., 2009; van Dillen et al., 2011). Other studies have used perceived (i.e. self-reported) measures of available green space (Putrik et al., 2014; Sugiyama et al., 2008) or used measures of access to green space, such as distance to the nearest green space (Carter and Horwitz, 2014; Reklaitiene et al., 2014). Since the first mortality study in Japan, several studies in the UK, USA and Canada have investigated associations between green space and mortality (Mitchell and Popham, 2008; Villeneuve et al., 2012).

The rapid growth of the number of epidemiological studies that have investigated the association between indicators of the availability of or access to green space in the immediate living environment and health justified a review. To date, there are many reviews that have aimed at synthesizing the evidence for the health benefits of green space. In their review of reviews, Hartig et al. (2014) concluded that the majority of reviews agreed that there is consistent evidence that more green space in the immediate residential environment is associated with better health, suggesting that health benefits of green space do occur, but that it is still unclear “when, where and for whom” the health benefits apply. However, several studies have demonstrated any association at all (Carter and Horwitz, 2014; Richardson et al., 2013) or found an association only for a specific subgroup and not for the general population (Reklaitiene et al., 2014; Richardson and Mitchell, 2010). Moreover, only few of the reviews were ‘full’ systematic reviews and, at the start of the current research project, none of them had focused explicitly on epidemiological studies that have investigated the overall relationship between green space and general health.

**Possible mechanisms underlying the health benefits of green spaces**

The Health Council of the Netherlands was the first to develop a conceptual model that defined possible mechanisms to explain the potential health benefits of green spaces. Besides the mechanism that green space might reduce stress and mental fatigue, for which the experimental evidence was judged as relatively strong and consistent, the Health Council (2004) hypothesized that green spaces may promote health by facilitating physical activity and social
contacts. However, studies that had investigated the relationships between green space and physical activity or social contacts were still scarce by that time, providing only weak evidence for those proposed mechanisms (Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, 2004).

Since then, several researchers have recognized the need to develop more advanced conceptual models which include mediators (i.e. intermediate variables related to mechanisms through which a determinant may influence the outcome), as well as moderators (i.e. variables that may change the determinant-outcome relationship) to guide future research (Hartig et al., 2014; James et al., 2015; Lachowycz and Jones, 2013; Nieuwenhuijzen et al., 2014). Two recently developed conceptual models are those of Hartig et al. (2014) and Lachowycz and Jones (2013). Hartig et al. (2014) developed a conceptual model that identifies physical activity, social contacts, stress and air quality as potential mechanisms linking green space with health. The researchers distinguish between indirect, behavioural mechanisms that involve the use of green space (or, in the model of Hartig et al., 2014 “contact with nature”) and mechanisms that directly affect health through air quality and stress level. They argue that the mechanisms might be multiple and synergistic. Furthermore, the model suggests effect modification by individual characteristics, such as age, gender, socio-economic status, and contextual factors (e.g. cultural and climatic context), indicating that the associations may vary between population subgroups and across cultures (Hartig et al., 2014). Based on summarizing the evidence for the four mechanisms, Hartig et al. (2014) concluded that many research questions remain largely unanswered, especially those concerning how to measure exposure to nature (i.e. “dose”) and those concerning better understanding of the mechanisms (or mediators), and how these are intertwined.

Another more complex conceptual model was developed by Lachowycz and Jones (2013). This framework draws on socio-ecological theories and illustrates how mechanisms of moderation and mediation could drive changes in healthy behaviours or psychological states which explain associations between availability of green space and health benefits. In line with Hartig et al. (2014), Lachowycz and Jones (2013) concluded that it is not clear yet which potential mediators and moderators act in the different proposed causal pathways that link green space with health outcomes. Especially, mediators related to use of green space for leisure activities, aesthetic pleasure and stress reduction from viewing, and improved perceptions of the neighbourhood as a whole, may explain associations between green space and health (Lachowycz and Jones, 2013). Few studies have included actual use of green space in assessing associations with health or health-related outcomes (Gascon et al., 2015). Therefore, it is not clear whether people’s intentional use of green space, for example for leisure purposes, might explain the associations between the availability of green space in the immediate living environment and health. Actual use depends on varies individual characteristics that are related to opportunity and motivations to use green space and on green space characteristics, such as type, quality and perceived safety as is described in the conceptual model presented by Lachowycz and
Jones (2013). Furthermore, associations that link green space with health outcomes could be subject to effect modification by individual (e.g. age, gender, social-economic status, dog ownership), social-cultural and other contextual characteristics (urbanity, infrastructure, climate), and by green space characteristics (e.g. type, size, objective and perceived quality, perceived safety) (Lachowycz and Jones, 2013).

Figure 1.1 shows a conceptual framework that attempts to combine the potential causal exposure pathways and mechanisms (or mediators) identified by Hartig et al. (2014) and Lachowycz and Jones (2013). Some of the arrows are bi-directional, indicating reciprocal associations. However, also other arrows might be bi-directional because of more complex relations and the influence of contextual socio-cultural factors not included in the framework.

![Conceptual framework linking green spaces with (physical and mental) health through different exposure pathways, and its potential causal mechanisms.](image)

**THIS THESIS**

As described above, previous research has provided indications for an array of possible health benefits of contact with or exposure to green spaces. Therefore, there is a need for systematically reviewing and synthesizing the level of evidence of health benefits of green space. Substantial knowledge gaps exist, of which those regarding the underlying mechanisms is the most notable. Challenges are to identify mediators and modifiers of the associations between green space and different health outcomes, and especially to clarify the intermediate role of use of green space as a proxy of exposure. Previous experimental research on the restorative quality of green space identifies a need to further explore the underlying psychophysiological...
mechanisms of mental health benefits, more specifically of stress recovery and buffering effects of exposure to green space.

The research presented in this thesis aims at addressing these knowledge gaps by using epidemiological as well as experimental methods. The aim of this thesis is threefold:

1. To systematically review and synthesize the evidence for associations between green space in the residential environment and perceived mental health, general health and all-cause mortality;
2. To explore effect modification and underlying mechanisms regarding the association between green space in the residential environment and mental health, using cross-sectional data collected across four European cities using time spent on visiting green spaces as a proxy of exposure and mental health as outcome (three epidemiological studies collecting and using PHENOTYPE data);
3. To explore the underlying psychophysiological mechanisms of mental health benefits of green space in an experimental study, with a focus on visual exposure.

**Project setting**

The research conducted for this thesis is part of the EU Seventh framework project “Positive health effects of the natural outdoor environment in typical populations in different regions in EUROPE (PHENOTYPE)”. The aim of PHENOTYPE is to seek more robust evidence for a relationship between exposure to natural outdoor environments and human health and well-being in different countries/regions across Europe. The project consisted of distinct, interdependent packages, which included: i) the characterisation of the green spaces, using a combination of methods (e.g. remote sensing, smartphones, audits and interviews) to establish several indicators of the availability and quality of green spaces; ii) the examination of the underlying mechanisms for the association between exposure to green and blue space (i.e. green urban and natural areas including all types of water bodies) and health in newly collected data in four European cities in different cultural and climatic settings: Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania) and Stoke-on-Trent (United Kingdom); iii) a series of epidemiological, secondary data analyses that used existing health data from registries and cohorts from different European counties/regions (Lithuania, the Netherlands, Spain and UK) to investigate associations between exposure to green spaces and a wide array of health outcomes; and iv) small-scale experimental studies to investigate short term changes in psychological and psychophysiological indictors in healthy and patient populations that were exposed to different environmental conditions. Nieuwenhuijsen et al. (2014) present a general overview of the research programme protocol and methodology.
Defining green space

In the PHENOTYPE project, the term “natural environment” was used. For the purpose of the project, green spaces included green as well as blue spaces. Thus, besides urban green spaces such as city parks and courtyards, and “greenery” (e.g. forests, nature parks, farmland, trees), also waterbodies such as canals, ponds and rivers were classified as green space. Although the term natural environment refers to an environment not made or controlled by humans, most of the green spaces included in the project were man-made and part of the urban environment. Therefore, in this thesis, the terms “natural environment”, “green space” and “green environment” are used interchangeably, referring to all types of public and private open spaces that contain “green” and “blue” natural features including all types of vegetation (e.g. trees, greenery, grass, forests) and all types of stagnant and running water.

Analytical framework for the epidemiological studies

The main focus of this thesis is on the association between green space and mental health. There are several reasons for choosing this focus. Firstly, mental health is a public health priority in Europe, where almost a third of the population is confronted with mental health problems at some point in life (World Health Organisation, 2013). Secondly, the psychological restoration/stress reduction mechanism is generally indicated as the most plausible mechanism underlying the association between green space and mental health because of the consistent evidence from experimental research (Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, 2004; Hartig et al., 2014). This is supported by studies that have found that associations were stronger for mental health than for physical health (Maas et al., 2009; Sugiyama et al., 2008). Other proposed mechanisms are mechanisms related to physical activity and social contacts, which hypothesize that green spaces enhance physical activities such as exercise, sports, active travel, and promote social contacts. It is well-known that physical activity and social contacts may reduce stress levels and, in the long term, affect mental health. Thus, by choosing mental health as outcome, the proposed mechanisms can be explored separately and in combination.

Figure 1.2 presents the analytical framework applied to explore effect modification and mediation by using the PHENOTYPE data. It describes the relationships between the determinants and outcomes, and the potential moderators and mediators investigated in the epidemiological studies in this thesis. A central pathway of exposure in this framework is purposeful visits to green space, which is operationalized as time spent on visits to those spaces and which combines information on two aspects of exposure, namely frequency of visits and duration per visit. Most previous studies on health benefits of green spaces have examined availability or access to green space, without addressing the actual use of green space. Lachowycz and Jones (2013) as well as Hartig et al. (2014) take use of green space (or contact with nature) into
account in their conceptual models as a proxy of exposure. However, it is not yet clear whether purposeful visits are needed. Mental health benefits may also occur as a consequence of greenness just being within view (see Figure 1.1).

In this thesis, the results of three epidemiological studies are presented. Firstly, the association between time spent on visiting green space and mental health was investigated, as well as whether this association differs between different population (sub)groups. Secondly, the mechanisms explaining the association were explored. Thirdly, it was examined whether time spent visiting green space is, as hypothesized in the analytical framework (Figure 1.2), an important exposure mechanism linking green space available in the residential environment with mental health. The specific research questions were the following:

1. How strong is the association between time spent on visiting green spaces and mental health? And do cultural/climatic settings and individual, demographic and motivational, factors modify the association?
2. Do physical activity and social contacts mediate the association between time spent on visiting green spaces and mental health?
3. Does time spent on purposeful visits to green space mediate the association between the level of residential greenness and mental health?

**Figure 1.2:** Statistical analytical framework
PHENOTYPE data collection

To answer these research questions, cross-sectional questionnaire data were used that were collected in the period from May till November 2013 in an adult population sample of 3947 respondents in total from 124 neighbourhoods in four European cities: Barcelona (Spain), Doetinchem (the Netherlands), Kaunas (Lithuania), and Stoke-on-Trent (United Kingdom). The questionnaire survey was designed to investigate three potential mechanisms: i) physical activity; ii) social contacts/cohesion; iii) psychological restoration/stress reduction. Included for each mechanism were questions on availability and use of green space to provide the opportunity for these activities and restorative experiences and the importance granted to them in general and, more specifically, to perform and experience them in green spaces. Furthermore, data were collected on the frequency and duration of visits to green spaces near home and further away, on satisfaction with several quantity and quality characteristics, including perceived safety, of green spaces, and on nature experiences during childhood. Finally, some questions on perceived health were asked (i.e. on general and mental health) and on residential and socio-demographic characteristics. Most questions were derived from existing and validated scales, for this thesis in particular: the Medical Outcome Study 36-item Short Form (SF-36) scales for assessing perceived mental health and vitality (Ware, 2000), the Short Questionnaire to Assess Health-enhancing physical activity (SQUASH) (Wendel-Vos et al., 2004), the social cohesion and trust scale (Sampson et al., 1997) and the UCLA loneliness scale Russell 1996). The questionnaire was developed to be consistently applied in a face-to-face interview, but in Kaunas, where data were collected with a postal questionnaire. See for more details on the data collection Nieuwenhuijsen et al. (2012).

PHENOTYPE used a combination of methods to collect data on the quantitative and qualitative characteristics of green spaces. For the selection of neighbourhoods with sufficient variation in access to green space, available land-use maps were used such as Urban Atlas (Barcelona, Kaunas and Stoke-on-Trent) and TOP10nl (Doetinchem). Remote sensing and aerial photography was used to calculate Normalized Difference Vegetation Indices (NDVI) as indicator of the level of greenness in circular buffers around the geocoded address of each participant.

Outline of this thesis

Chapter 2 presents one of the first systematic reviews of epidemiological studies that have examined associations between quantity and quality of green spaces in the living environment and perceived general health and mental health, and all-cause mortality. The selected studies were assessed regarding their methodological quality and, if possible, were included in an evidence synthesis for each health outcome separately. Besides the results for general populations, the results for subgroups were reported to identify differences. Chapter 3 to 5 present the studies that explored effect modification and mediation using the PHENOTYPE data. Chapter 3 describes
the cross-sectional study that focussed on the association between self-reported time spent in green spaces during purposeful visits and (1) perceived mental health and (2) perceived vitality. In addition, chapter 3 presents the results of effect modification by city and by several socio-demographic factors (gender, age and level of education), and motivational factors (attitude towards green space and nature childhood experience). Chapter 4 focuses on the mediation analyses that were conducted to test whether different indicators of physical activity and social contacts mediate the association between time spent visiting green spaces and mental health, either separately or in combination. Chapter 5 addresses the research question whether time spent visiting green spaces mediates the associations between residential greenness and mental health. Chapter 6 describes the laboratory experiment conducted to explore psychophysiological stress buffering and recovery responses during brief visual exposure to photos of urban green spaces compared to built spaces. Finally, the General discussion (Chapter 7) summarizes the main results, discusses methodological issues as well as of the implications of the research results for policy and practice, and it gives recommendations for future research.
REFERENCES

Barton, H. 2009. Land use planning and health and well-being. Land Use Policy, 26(0), S115-S123.


