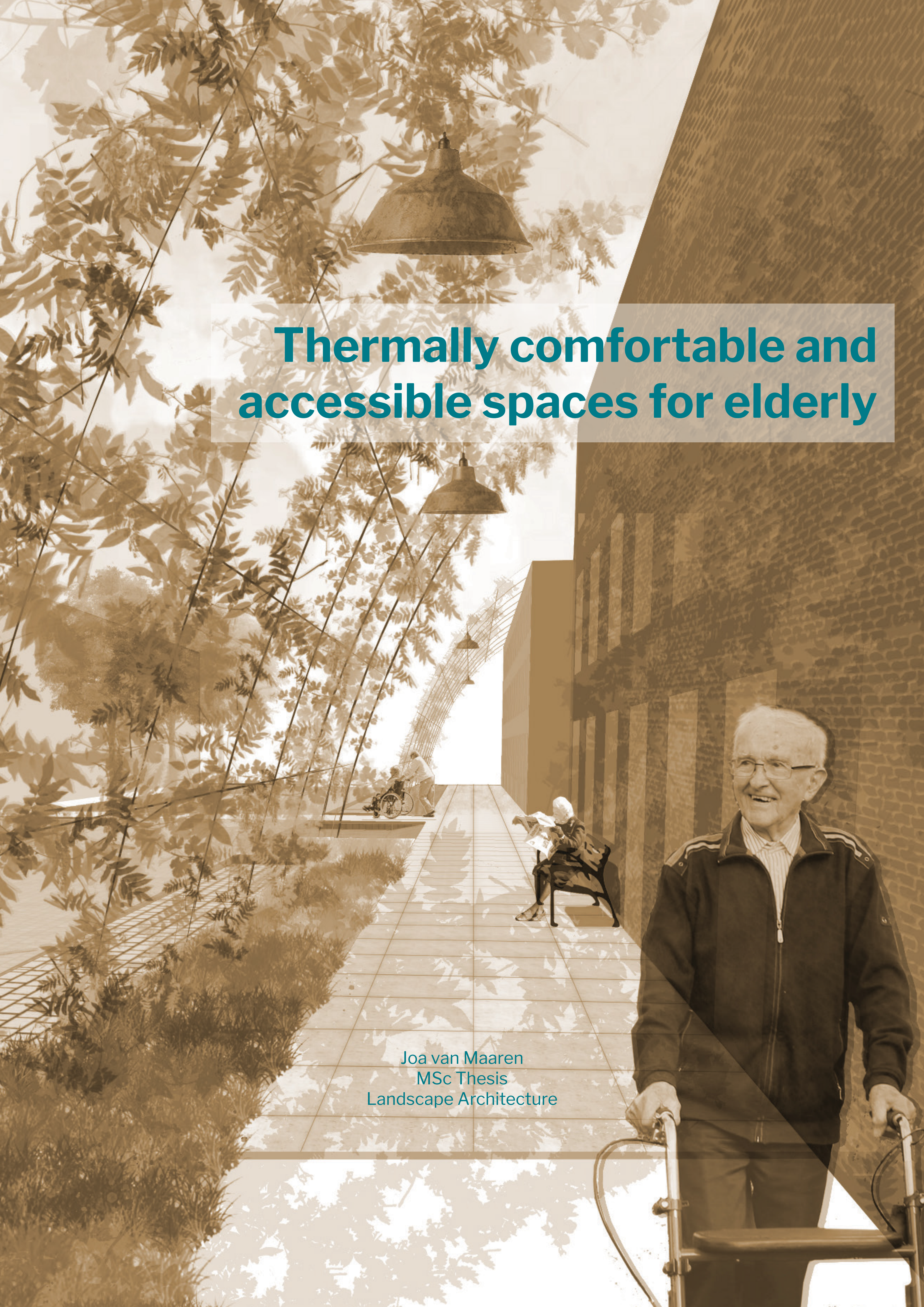

Thermally comfortable and accessible spaces for elderly

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MSc Thesis
Landscape Architecture

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Abstract

In the coming years we will have increasing numbers of elderly in our urban environments in the Netherlands. With greater life expectancy, the ability of elderly people to function independently is becoming an increasingly important public health issue. Cities should be made more aging-proof and suitable for elderly to continue to live at their own homes. Numerous scientific studies show that enough physical activity has a beneficial effect on the health, the self-reliance and the well-being of people, even at very high age. However, a large amount of elderly are not active enough. One of the reasons that elderly are not physically active enough is the bad quality of the public space. Therefore it is very important to make public spaces accessible for elderly.

A big threat for public health, and especially for the vulnerable such as elderly, is the changing climate. The heat load in urban surroundings forms a health risk. Not only the mortality rates rise, but also other health problems increase. To mitigate the urban heat island effect and to be able to cope with heat stress, landscape architects can contribute with climate responsive design. Site-specific measures can create thermally comfortable spaces.

This research examined how we can make accessible and thermally comfortable residential streets for elderly. In a research through design process was tested how design principles can improve the accessibility for elderly and how design principles can improve the thermal comfort in residential streets. These design principles are assessed on the criteria safety, connectivity, legibility, providing shadow, cooling by evaporation and evapotranspiration, and minimising heat accumulation. The best solutions were used to develop integrated design principles that are both accessible for elderly and thermally comfortable. The research findings show that different design principles can be very well combined and complement each other. To reach an accessible space for elderly, multiple design principles are needed that together form an optimal situation. This resulted in green residential streets with enough space for elderly. It is a step towards more climate responsive design with a focus on vulnerable groups in our society.

Preface

This thesis has come about with great pleasure and effort. As a student in landscape architecture I always intended to use my research and design skills for the benefit of problems in our society. I believe that landscape architects can play a major role in connecting different disciplines, improving our public spaces and quality of life. I was always interested in the phenomenon climate change and think there is still a great challenge in making adaptation measures more self-evident and important. Also social challenges have always interested me and have made me think of how to include all types of people in our society. This is not so easy, because every group of people, every person, has different needs and opinions.
Within this thesis I tried to contribute to some of these challenges by researching and designing for one aspect within the topic of climate change, heat stress, and one vulnerable group in our society, elderly. I found out that the relationship between heat stress and this growing group is very sensitive and asked for new knowledge. With this thesis I hope to contribute to this and inspire landscape architects and other involved persons to take action.

During the process of this thesis I came across many struggles, such as wanting too much in too little time and encountering unexpected outcomes. Luckily I had some great support by my side. My supervisors Sanda Lenzholzer and Carlijn Wentink helped me throughout the process to keep me on the right track. Sanda helped me with her enthusiasm and extensive knowledge on climate responsive design. She gave me very valuable suggestions on how to tackle problems and always asked the right questions about this research. Carlijn helped me with her knowledge in the field of health of elderly and helped me to get acquainted with this new topic. Her comprehensive feedback and good suggestions on the written report were also of great importance.

I would also like to thank my peer students, who felt as allies and helped me by giving good advices and strong opinions. They asked the right questions and helped me bringing the thesis to a higher level. A special thanks goes to Nina, with whom I started the thesis process at the same time as part of the ClimAtelier. Our conversations, brain storm sessions and mutual encouragement were very important for the progress of my thesis and helped me to challenge myself and get the best out of it.

I also want to thank my dear family, my boyfriend and my friends for the big support throughout the process. It was not always an easy road to walk, but you encouraged me and expressed your understanding. A special thanks to my parents, my sister and my boyfriend with helping me with this thesis by reading along, joining me on excursions and giving their opinions. I also want to thank my grandmother and grandfather, who inspired me to pick this topic. Because you broke your foot through a loose tile and fell over your rollator because of a high curb, I was convinced that this problem was one to not forget. Also your feedback on the design for improving the accessibility of the public space, helped me getting bright insights.

Looking back at the establishing of this thesis, I am satisfied with the result and the contribution it makes to the scientific and societal world. I hope my thesis inspires many people to see the importance of addressing this topic and actual make work of it.

Contents

chapter 1 | introduction

1.1 Problem introduction

An ageing society

In the coming years we will have increasing numbers of elderly in our urban environments. In the Netherlands, the amount of people who are 65 years and older will increase from 2,6 million to 4,5 million between 2010 and 2050 (Zantinge et al., 2011). A quarter of the population is then 65 years or older. The life expectancy will continue to rise. In 2050, 40% of the elderly will be 80 years or older (Zantinge et al., 2011). With greater life expectancy and an increasing proportion of elderly people within the general population, the ability of elderly people to function independently is becoming an increasingly important public health issue (Borst et al., 2008). However, the healthcare system in the Netherlands is also changing from residential care and elderly homes into a system of care without residence. This means that people will have to stay at home longer, with health care at home and customised for each individual (Van der Kooij, 2015). Municipalities are researching how they can organise these changes and are aiming at new policies and strategies to make it easier for elderly to live longer in their own homes and stay longer independent (Van der Kooij, 2015).

The responsibility for someone's own health care has moved back from the government to the citizen. This is what we call the participation society. On the other hand we are also turning more into a prevention society: the government is caring more about the lifestyle of its citizens (Vanstiphout, 2016). The prevention society promotes healthy ageing. Healthy ageing is not only focused on preventing and postponing illnesses and mortality, but focuses on preventing and postponing constraints in functioning and promoting self-reliance, participation and good quality of life (Zantinge et al., 2011). Corburn (2015) suggests a more integrated approach to use 'city planning as preventive medicine'. The built environment plays an important role in influencing lifestyle choice. This means that designing an attractive, green and open city is of importance to the public health. Designers can help prevent people from getting diseases, but also help to avoid welfare diseases like diabetes, obesity, cardiovascular and respiratory problems, and depression (Vanstiphout, 2016). Cities can be made more aging-proof and suitable for elderly to continue to live at their own homes.

This thesis is about a specific group in our society, elderly. The definition of **elderly** in this thesis is

older adults that are:
- 65 years or older (Zantinge et al., 2011)
- Vulnerable, which means that there is a process of "the accumulation of physical, psychological and/or social deficits in the functioning that increases the chance of negative health outcomes" (Campen, 2011, p. 45)
- Self-reliant and independent, to still be able to stay living at home (Molster, 2015).


Nederland veroudert en dat merken vooral de naoorlogse woonwijken. De risico's voor ouderen: problemen met stoepen, hoge opgangen en vereenzaming. Hoog tijd voor plannen om Nederland vergrijzingsbestendig te maken.
Door Jochem van Staalduine

Klaar voor de grote vergrijzing

De opdracht: behandel ouderen niet als zielige mensen, laat ze meedoen
Floris Alkemade

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Figure 1. Newspaper article in the Volkskrant, may 2017.

Staying physically active

In order to be able to stay living at home and age healthy, elderly should be physically and mentally fit. The research of Saelens and Handy (2008) says that "walking is one of the most common forms of physical activity, with documented benefits for health". It is the most ageing-proof mode of transport (Molster, 2015). Staying mobile means freedom, independency and self-reliance (Molster, 2015). Besides that, moderate physical activity is needed to prevent the decrease of functional status and reduces the chance on illnesses (Van Staalduinen, 2014). Numerous scientific studies show that enough physical activity has a beneficial effect on the health, the self-reliance and the well-being of people, even at very high age. Aging is associated with a reduction of the physical spare capacity, which is a safety margin during age-related, disease-related or other negative influences. An inactive lifestyle is generally seen as a catalyst for the reduction in spare capacity. Adequate physical activity is seen as an effective method to prevent or reduce aging restrictions (de Vreede et al., 2008).

However, a large amount of elderly are not active enough. In the Netherlands 48% of the women and 34% of the men older than 65 from 2001 to 2006 were not having enough exercise (Borst et al., 2008). Elderly should at least three days a week be heavy intensive physically active for 20 minutes or at least five days a week moderate intensive physically active for 30 minutes (such as walking or cycling) (Zantinge et al., 2011). Also loneliness is regarded as bad for the health of elderly. It can lead to more stress, higher blood pressure and bigger chance on depressions. Therefore, meeting other people is very important for ageing healthy (Van Staalduinen, 2014).

An accessible public space

One of the reasons that elderly are not physically active enough is the bad quality of the public space. Every year, 18.000 elderly need emergency care after they fall on the street, this means that every 30 minutes someone falls (Boeijen, 2016). In 2016, 3884 people died because they fell and this number is increasing every year (NOS, 2017). Elderly experience problems with the accessibility of outdoor public spaces. 58% of these falls are caused by environmental factors (Boeijen, 2016). Often these problems are linked with safety issues. Many pedestrian falls are caused by barriers and obstacles in the public space (Stahl et al., 2008). Due to a lower mobility of elderly, they are more dependent on their immediate living environment. The public space should make it possible for everyone to move around freely (Molster, 2015). Therefore it is very important to make public spaces accessible (Balfour & Kaplan, 2002; Borst et al., 2008; Prins et al., 2016). Older people walk more when the neighbourhood is highly walkable. Research also shows that green, functional design and levels of safety contribute to a higher walkability (Prins et al., 2016; Thompson, 2013). The lay-out of the physical environment influences their lifestyle and also their social well-being, for instance by meeting each other in public spaces (Hoeymans et al., 2010). A neighbourhood with low quality public spaces can result in a higher probability of inactivity of elderly and thus a bigger risk for elderly to lose physical functioning (Balfour & Kaplan, 2002; Borst et al., 2008; Prins et al., 2016). Interventions in the public space can support positive changes in someone's behaviour towards physical activity (Pearce & Maddison, 2011).

Health threatened by climate change

A big threat for public health, and especially for the vulnerable such as elderly, is the changing climate. We are facing serious climate change, with big effects on our daily lives and the liveability in a dense city (Van Hove et al., 2011). It forms an evident risk for our environment and reduces the chance on ageing healthy. Extreme weather events such as heat waves occur more often and affect all continents of the world (Kirch et al., 2005). In Europe, from 1990 to 2010, 16 of 20 winters and 19 of 20 summers had an above average temperature. Since 2000, there were twice as many records of high temperatures than records of low temperatures (Kenney et al., 2014). Globally, heat waves have increased in frequency, duration and severity. It is 50-100 times more likely that there occurs a heat wave over the last three decades. The prediction is that this increases even more in this century (Kenney et al., 2014). The Royal Netherlands Meteorological Institute (KNMI), developed four climate scenarios which predict that summers will have more tropical nights with a minimum of 20°C or higher and more hot days with a maximum temperature of 25°C or higher (Klein Tank et al., 2015).

The heat load in urban surroundings forms a health risk for vulnerable groups of people, such as elderly and chronically ill people. Not only the mortality rates rise, but also other health problems increase (Boer, 2010) such as more heat related illnesses (RIVM, 2012). In dense city centres the urban heat island effect (UHI) will become more sensible. The urban heat island effect means that cities are warmer than the rural areas in the surroundings (Harlan et al., 2013). There exists a difference in (higher) air temperature between the city and the rural areas of sometimes almost 10°C, because of the absorption of heat (Kleerekoper et al., 2012; Van Hove et al., 2011). Dutch cities were not considered as places where the Urban Heat Island (UHI) would be important (BRON). However, after the heat waves in 2003 and 2006, this view altered because of an excess mortality between 1400 and 2200 elderly and chronically ill. Cities in the Netherlands are known for their high density, so then you can expect that the UHI plays a role (Van Hove et al., 2011).

Heat stress

Heat waves and the effects of an urban heat island form a health risk for elderly in the Netherlands. This leads to more emergency room visits (RIVM, 2012) and especially among individuals older than 65 years (Kenney et al., 2014). According to Havenith (2005), “heat related mortality and morbidity are strongly linked to age”. People will suffer more from the heat when the period with extreme temperatures is lasting long and when the outdoor temperature is much higher than a threshold temperature. This is enhanced by sleep shortage due to heat during the nights, whereby people cannot rest enough. Persistent heat for longer periods can cause serious health effects (RIVM, 2012). In Northern European cities, mortality increases with 1,84% when the apparent temperature increases with 1°C above a threshold temperature (Kenney et al., 2014) which varies among cities (Baccini et al., 2008). This can also be seen in the graph (figure 2) of Baccini et al. (2008). Most heat-related deaths occur in cities because they experience an urban heat island effect (Harlan et al., 2013). Also socioeconomic and living conditions are of big influence. The probability of death during heat waves occurs when people are elderly, confined to bed and sleep on the top floor of their building. Also lack of thermal insulation and living in an urban heat island contributes to the odds of death (Kenney et al., 2014).

The risk of dying from heat is much greater for older people. In some cases, more than 90% of the deaths during heat waves are elderly (Kenney et al., 2014). In most cases the excess morbidity and mortality during heat waves are not a direct effect of the heat, but are cardiovascular defects (the system of the heart and blood vessels). This is because of the cardiovascular challenge to have a thermoregulatory response to heat stress (Kenney et al., 2014). Elderly, even when they don’t have a cardiovascular disease, are the most vulnerable group in long periods of heat exposure and they experience significantly worse health effects than people of other ages (Kenney et al., 2014). The earlier mentioned physical ‘spare capacity’ of elderly needs to be in order to be able to cope with these effects. Physiological strain on other systems is also considered as a cause of raised mortality. Also respiratory and cerebrovascular deaths cause a higher mortality during heat waves (Kenney et al., 2014). Dehydration and chronic diseases like diabetes also form an extra mortality risk (RIVM, 2012).

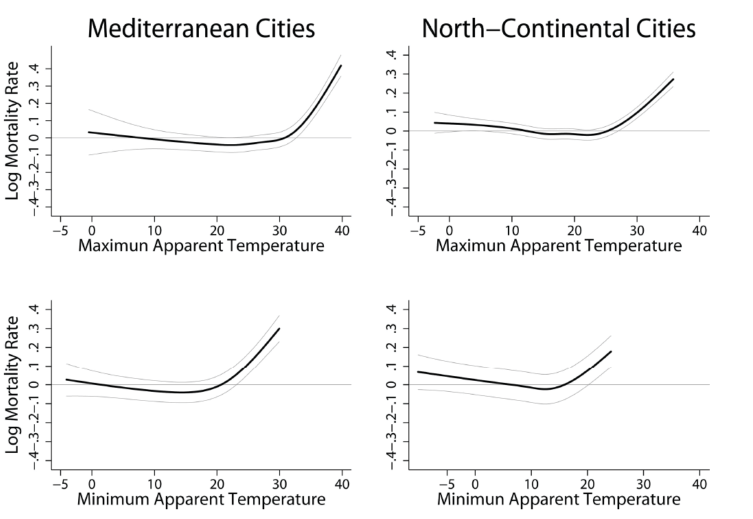


Figure 2. Fixed effects curves describing the adjusted effect of daily maximum and minimum apparent temperature on mortality (Baccini et al. 2008).

The heat balance of the human body is affected by climatic parameters, such as air temperature, wind speed, humidity and radiant temperature. Also personal parameters like sweat capacity, clothing insulation and activity rate affect the tolerance for heat (Havenith, 2005). Humans experience a substantial stress on the cardiovascular system, when they are prolongedly exposed to high ambient temperatures. Although people are capable of repelling very high temperatures for a short period, cardiovascular strain can be induced by heat exposure. This can contribute to negative health outcomes (Kenney et al., 2014). Thermoregulatory control inside the body should regulate the body temperature and keep it stable, this is schematically represented in figure 3 (Havenith, 2005). To expel heat in order to protect against increasing core temperature, the skin blood flow and sweat rate are increasing. This is necessary for thermoregulation of the human body, but ask a lot of the cardiovascular system (Kenney et al., 2014). Older people have trouble with regulating their evaporative heat loss, which results in greater heat storage. Their sweat rate and sweat output per gland decreases, because of a drop in the dermal circulation (Kenney et al., 2014).

Climate responsive design

To mitigate the urban heat island effect and to be able to cope with heat stress, landscape architects can contribute with climate responsive design: “Planning and design can influence the urban climate on the scale of the entire city” (Lenzholzer, 2015, p. 54). On the smaller scale, landscape architects can also think of climate adaptive measures in the public space to adapt the microclimate. Site-specific measures can create thermally comfortable spaces. Many small interventions can have a big effect together and can already be felt on a small scale (Lenzholzer, 2015). Making the city and its public spaces more green is reducing the urban heat island (Arnberger et al., 2016) and helps to reduce vulnerability to heat stress (Brown et al., 2015). This will have a substantial effect on human thermal comfort (Brown et al., 2015). Heat stress is a broad problem and occurs almost every summer. Also during less extreme weather events, the public space should be thermally comfortable.

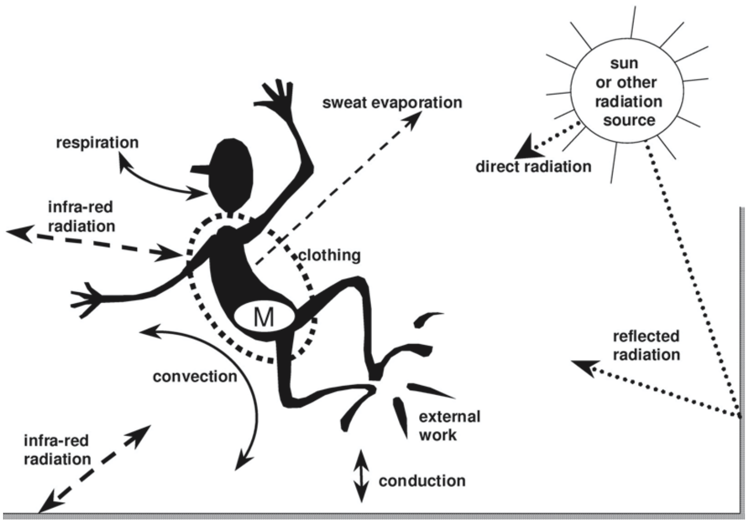


Figure 3. Schematic representation of the pathways for heat loss from the body. M = metabolic heat production (Havenith, 2005).

Conclusions

With the increasing numbers of elderly in the Netherlands there is a need for accessible public spaces to encourage them to stay physically active. By being physically active, they improve their health and enlarge their physical spare capacity that can repel negative health outcomes. One of the biggest threats for the health of elderly is the changing climate and the increasing heat waves. Especially heat stress is causing a lot of heat related illnesses and higher mortality rates.
This is an opportunity for landscape architects to think of public spaces that are both accessible for elderly and improving the thermal comfort during warm weather circumstances. These public spaces could encourage elderly to go outside be physically active and at the same time contribute to minimising the urban heat island effect. In this way landscape architects can improve the health of elderly by improving the public space.

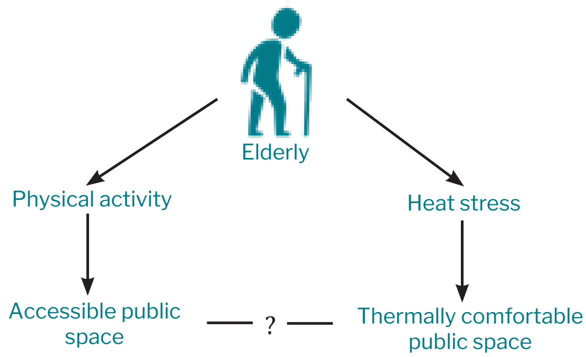


Figure 4. The problem statement.

1.2 Knowledge gap

I reviewed different literature in the field of climate change, in the field of landscape architecture and urban design, and in the field of health issues concerning elderly. It appears that there is a lot of information available about the urban heat island effect and climate change causing more heat waves. There are theories about how to minimise the urban heat island effect and improve thermal comfort in our cities. Research shows that heat waves affect our society and induce serious health issues such as heat-related illnesses, excessive morbidity and mortality, especially among elderly. To be able to ward off these negative health outcomes, elderly should be physically active and therefore need an accessible outdoor space. Especially their immediate living environment appears to be very important, because elderly have a lower mobility. There are theories how to design for vulnerable groups such as elderly, because this asks another approach than when we design for the average healthy person. We also know that green outdoor spaces positively contribute to minimising this urban heat island effect. Landscape architects and urban designers develop tools how to design these green spaces and make a city more climate-responsive.

However, there is not much information or guidance how to design public spaces that are both accessible for elderly and thermally comfortable. There occurs friction between giving greenery enough space in the urban landscape to minimise the urban heat island effect and giving the elderly enough (paved) space to walk around their neighbourhood safely.

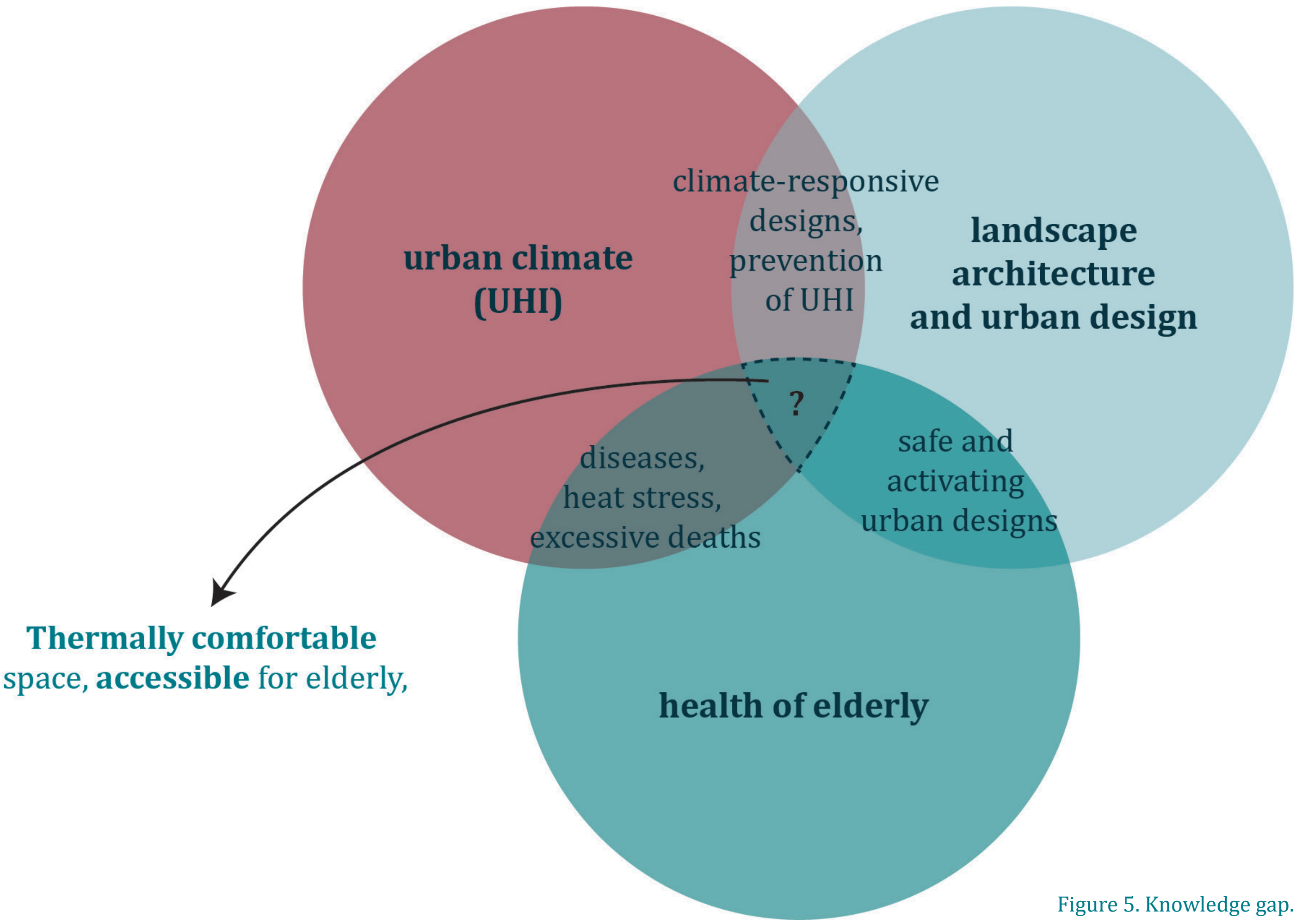


Figure 5. Knowledge gap.

1.3 Research objective

Landscape architects and urban designers need to consider the vulnerable groups in our society in their climate responsive designs. The main objective of this research is to find out what is needed to make public spaces both accessible for elderly and thermally comfortable, and create design principles as part of a research through designing process. These design principles give guidance in designing thermally comfortable and accessible spaces for elderly. The research will focus on residential streets, since elderly have a lower mobility and therefore are limited to their immediate living environment. The design principles should form new knowledge which is applicable on different problematic sites. These sites should become comfortable, usable spaces for elderly in which they can actively participate in their neighbourhood.

1.4 Research questions

MRQ: What design principles can be developed to improve thermal comfort and accessibility for elderly in residential streets?

To be able to answer the main research question, the research will be supported with two sub research questions:

SRQ1: What design principles make a street thermally comfortable?

SRQ2: What design principles make a street accessible for elderly?

chapter 2 | theoretical framework

2.1 Introduction

The problem introduction makes clear that we will have to deal with growing numbers of elderly in the Netherlands. Elderly continue to live at home longer and therefore their immediate living environment needs to be accessible. Walking is the most favoured form of physical activity, which contributes to a better health. It is very important for elderly to be mobile, because this means that they are free to go where they want and that they are independent. In chapter 2.2 the term accessibility will be further studied within the literature.

Climate change has negative effects on the health of elderly. Heat stress is causing heat-related illnesses and higher mortality rates. Climate responsive design can contribute to a more thermally comfortable public space and minimise the negative effects of heat stress. Even in summer when the sun is shining bright, elderly should be able to walk to the supermarket. In chapter 2.3 thermal comfort will be further studied within the literature.

In this chapter I will explore what literature says about improving thermal comfort at street level and what it means if a street should be accessible for elderly. This literature study will provide me criteria that I will use to evaluate the design principles.

2.2 Accessibility

Definition

Elderly often experience accessibility problems in outdoor environments (Stahl et al., 2008), because designers have the average healthy young adult in mind (Burton & Mitchell, 2006). But inaccessibility can make it difficult for people with mobility impairments or other disabling conditions to move around their neighbourhood. Consequently, people with these problems are more vulnerable to environmental barriers (Mohammad & Abbas, 2009). This can restrict elderly in their activities or even force them to stay at home.

Accessibility can be defined as:
"the extent to which streets enable older people to reach, enter, use and walk around places they need or wish to visit, regardless of any physical, sensory or mental impairment" (Burton & Mitchell, 2006, p. 92).

The physical environment can make a positive contribution to healthy ageing by making it more 'age-friendly' (Zantinge et al., 2011), by making the physical environment accessible for elderly. The design of the streets, functional design for sidewalks, the availability of parks, the materials and the state of maintenance are all determining if elderly use the space or not (Hoeymans et al., 2010). The measures to be taken, should help elderly live healthy such as having more physical activity and remaining independent (Van Staalduinen, 2014). Although someone's beliefs in the benefits of physical activity could be very positive, the real and perceived barriers determine if someone actually becomes physical active. Barriers can be internal or external. This means that it can be personal, such as a lack of motivation, but it can also be restricted by weather conditions or physical environmental aspects (Kosteli et al., 2016).

Factors contributing to accessibility

In literature many factors were mentioned that contribute to an accessible public space for elderly. For instance the quality of the pavement, the degree of maintenance, safe crossings, height differences on the sidewalk, the availability of benches to take a rest, obstacles on the sidewalk or no clear overview over the street are all contributing to how accessible the public space is for elderly (Borst et al., 2008; Moran et al., 2014). Also the fear of becoming involved in a traffic accident or becoming lost is not positively contributing to the experienced accessibility of a public space (Burton & Mitchell, 2006). Besides that, research shows that elderly also mention the presence and continuity of sidewalks are very important (Pikora et al., 2006). Also the separation between pedestrians and other transport modes was mentioned as desirable (Moran et al., 2014).

This literature study delivered a long list of all factors that influence the accessibility of public space for elderly. These aspects can be categorised. Many of the factors are linked with safety issues (Mahmood et al., 2012; Zantinge et al., 2011; Borst et al., 2009; Stahl et al., 2008; Michael, Green & Farquhar, 2006; Burton & Mitchell, 2006). Other factors contribute to a well-connected network or continuity in a neighbourhood, these can be categorised under the term 'connectivity' (Moran et al., 2014; Borst et al., 2008; Burton & Mitchell, 2006; Michael et al., 2006). Elderly also benefit from a clear, structured public space where they can have a good overview and do not get lost. The factors contributing to this, can be categorised under the term 'legibility' (Moran et al., 2014; Borst et al., 2008; Burton & Mitchell, 2006).

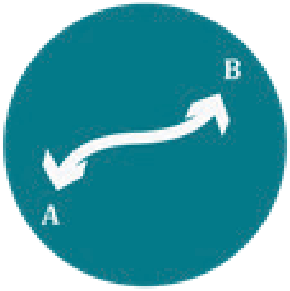
SAFETY | safe infrastructure

To make a space accessible it should be safe, especially for people with physical impairments. Elderly can be frail and have reduced mobility or an unsteady gait (Burton and Mitchell, 2006). The lack of safety is a barrier to physical activity (Franzini et al., 2010). Safety even emerged in several different studies as the biggest concern of elderly which limits their walking for everyday activities as well as exercise (Mahmood et al., 2012; Michael, Green & Farquhar, 2006; Burton & Mitchell, 2006; Borst et al., 2009).

Safety can be defined as:
"the extent to which streets enable people to use, enjoy and move around the outside environment without fear of tripping or falling, being run-over or being attacked" (Burton & Mitchell, 2006, p. 115).

Concerns about traffic and inadequate pedestrian infrastructure limit walking and other activities in neighbourhoods by making older adults feel unsafe (Michael et al., 2006). The physical infrastructure must not have obstacles that stands in the way (Cammelbeeck et al., 2014) and the pavement should be smooth and well-maintained, because this stimulates walking behaviour (Borst et al., 2008; van Staalduinen, 2014). Many pedestrian falls are caused by barriers and obstacles in the public space (Stahl et al., 2008). At crossings, sidewalks should have dropped curbs. Vehicles parked (half) on the sidewalk are also contributing to an unsafe situation (Höppner et al., 2014; Cammelbeeck et al., 2014).

Not only physical safety is important for elderly, but also psychological and social safety plays a role (Prins et al., 2016; Thompson, 2013). Once elderly fell over loose tiles, some have fear to go out as often or alone. Some elderly are also afraid of being run-over by traffic (Burton & Mitchell, 2006). Elderly also fear criminal activities or being attacked (Moran et al., 2014). In design, it can be taken into account that there is good lighting at night and no sense of enclosure or concealment (Borst et al., 2008). Closed views are perceived to be unsafe and reduce elderly's incentive to walk (Borst et al., 2009).



CONNECTIVITY | pedestrian network well-connected

To make streets accessible for elderly, sidewalks should be present at all places and continuous through the whole neighbourhood without abrupt endings (Moran et al., 2014). A well-connected pedestrian network positively influences the choice for walking (Borst et al., 2009).

Connectivity can be defined as:
"physical and visual connections—from building to street, building to building, space to space, or one side of the street to the other—that tend to unify disparate elements. Tree lines, building projections, and marked crossings all create linkage. It can occur longitudinally along a street or laterally across a street" (Ewing & Bartholomew, 2013, p. 19).

A well-connected pedestrian network is important for its effect on proximity, there are more direct routes and thus shorter distances to destinations. It could also influence the choice of routes and give more variety (Saelens & Handy, 2008). Pedestrian facilities such as crossings, bus or tram stops and places to rest are very important for a well-connected network (Thompson, 2013; Borst et al., 2008).

Research shows that a well-connected network has positive effects on physical activity and related health outcomes. High street connectivity makes destinations easier to reach and decreases the reliance on other forms of transport (Pearce & Maddison, 2011).

LEGIBILITY | legible and clear pedestrian infrastructure

To make urban space accessible for elderly, it is essential that streets are recognisable and easily understood by elderly. They should be hierarchical and have features that are familiar to older people (Burton & Mitchell, 2006). This can be done with a clear and legible pedestrian infrastructure (Moran et al., 2014).

Legibility can be defined as:
"the extent to which streets help older people to understand where they are and to identify which way they need to go" (Burton & Mitchell, 2006, p. 64)
and
"legibility refers to the ease with which the spatial structure of a place can be understood and navigated as a whole. The legibility of a place is improved by a street or pedestrian network that provides travellers with a sense of orientation and relative location and by physical elements that serve as reference points" (Ewing & Bartholomew, 2013, p. 18).

The comfort of knowing where they are, is contributing to the pleasure of elderly of trips out of the home and keeping their independency and self-esteem (Cammelbeeck, 2013). It is important that the urban space is well-structured and coherent (Borst et al., 2008). A clear zoning of the street which is understandable could contribute to this (Cammelbeeck et al., 2014). Crossings should be clear and there should be hierarchy (Philipson et al., 2013). A legible and clear infrastructure should also provide a better sense of orientation. The use of reference points, environmental features or landmarks helps to find the way around (Mohammad & Abbas, 2009; Burton & Mitchell, 2006).

It is important that making changes in streets should be made on a small-scale and should be incremental to prevent confusion (Burton & Mitchell, 2006).

2.3 Thermal comfort

Definition

When people go outside, they have a personal preference for a certain microclimate and they try to find a place that suits them. People choose a place with sun or shadow, with or without wind (Lenzholzer, 2015). Thermal comfort can be seen as a subjective, personal satisfaction with the thermal environment. This can be affected by several physical and psychological factors. This can be perceived differently by each person, which will make it difficult to specify an environment which suits everyone (Cortesao et al., 2012). During extreme hot weather conditions, people's thermoregulation is disturbed (Lenzholzer, 2015). Most people stay in their apartments when it is hot, because they think it is cooler inside than outdoors. 80% of the elderly stay inside during warm weather (Le Grand et al., 2014). Only some people go outdoors, mostly visiting green spaces. But if a neighbourhood is less attractive or safe, people stay at home (Arnberger et al., 2016). Designing (more and better) green spaces in a city can help reduce heat stress in two ways: they have a measurable cooling effect on the urban microclimate and they are providing public, adjusted and cool green spaces which are accessible for elderly on hot days (Arnberger et al., 2016). In other words, climate and city have a reciprocal relationship. Climate influences how the city space is being used and the city influences its climate (Kleerekoper et al., 2012).

Thermal comfort can be defined as:
"that condition of mind which expresses satisfaction with the thermal environment" (Cortesão et al., 2012, p.2), ***related to "thermo-physiology, i.e. physiology and the heat balance of the human body"*** (Taleghani et al., 2015, p. 65), ***affected by several physical parameters*** (Cortesão et al., 2012, p. 2).

These thermal environmental parameters are air temperature, radiant temperature, wind and air's relative humidity (Taleghani et al., 2015; Lenzholzer, 2015). High temperatures are experienced through air temperature but also through short- and longwave radiation. Shortwave radiation is the direct radiation from the sun. Longwave radiation is indirect radiation through materials that absorbed and later release the heat again (Kleerekoper et al., 2012). So the earth or materials absorb the shortwave radiation and emit it later as longwave radiation (Lenzholzer, 2015). Air temperature is something we cannot influence so much with design interventions on a small scale. The temperature difference between a sunny spot and shadow a few meters away is not very sensible. Only when you combine a lot of small interventions, then it could have a big effect. How we feel radiation or the radiant temperature could be changed with small design interventions on a small scale. Walking from a sunny place into a shaded place feels very different. And sitting in front of a warm wall after a sunny day is an example of feeling radiant temperature (Lenzholzer, 2015). Air's relative humidity is the amount of moisture in the air and can be influenced by vegetation and water. Influencing wind asks for other interventions, often at the scale of the entire city, or in parks and big squares.

Factors contributing to thermal comfort

In literature many factors were mentioned that contribute to thermal comfort. This research will focus on the climatic parameters air temperature, radiant temperature and air's relative humidity, because these parameters are directly sensible by climate responsive design on a small scale. Blocking short- and longwave radiation by creating shaded places is a very effective way to improve the thermal comfort (Brown et al., 2015; Lenzholzer, 2015). However, thermal comfort can also be reached through minimising the accumulation of heat in materials. This will help cities mitigate the urban heat island effect, but is also sensible at street level (Brown et al., 2015; Lenzholzer, 2015; Kleerekoper et al., 2012). Also actively cooling the environment by evaporation and evapotranspiration with vegetation has a positive effect on air's relatively humidity and thus on thermal comfort (Brown et al., 2015; Lenzholzer, 2015; Kleerekoper et al., 2012).

PROVIDING SHADOW

Shading is the most effective measure to cool the microclimate (Brown et al., 2015; Lenzholzer, 2015). Shading interventions enhance thermal comfort and reduce vulnerability to heat stress during warm weather conditions (Brown et al., 2015). Shortwave solar radiation can be blocked with objects that provide shade. Shadow is immediately sensible. The effect is dependent of the characteristics of the elements that casts the shade. Buildings and non-transparent objects have the deepest shadows. Transparent objects and trees cast less shade, but that is depending on the density (Lenzholzer, 2015).

The amount of shadow casted is also influenced by the season and the location on earth (Lenzholzer, 2015). The altitude angle of the sun changes during the different seasons in the Netherlands. The 21st of June is the longest day and then the sun has the highest altitude angle and thus objects give the smallest shadow. So in order to improve thermal comfort, interventions should also provide shadow during these circumstances.

MINIMISE HEAT ACCUMULATION

The second most effective measure is diminishing the accumulation of heat. Cities can mitigate the urban heat island effect by preventing a lot of absorption of heat (Kleerekoper et al., 2012). Reducing the amount of pavement and extending green spaces with 10% will make a difference of 1°C. Also increasing the albedo or emissivity of materials helps to lower the temperature (Klok et al., 2010). The reflectivity of a material is called albedo. The more a material reflects radiation from the sun, the material will warm up more slowly. Every material has different heat storage and release characteristics. The emissivity tells something about the ability to release stored heat with longwave radiation. The conductivity of a material is reflecting how fast a material can absorb and release heat (Lenzholzer, 2015).

If a material has a dark colour, more solar radiation will be absorbed and it will reflect less. The dark material will thus warm up more than other surfaces. The lighter the colour of a material, the cooler it stays (Brown, 2010).

COOLING BY EVAPORATION AND EVAPOTRANSPIRATION

Improving thermal comfort is also possible through cooling by evaporation and transpiration. Water (for instance waterbodies or water in the soil) can cool the air temperature by evaporating. In fact, with the evaporation of water the warming up of the air is reduced (Lenzholzer, 2015). Vegetation cools the environment actively by evaporation and transpiration: evapotranspiration. The leaves of plants can evaporate water through the stomata (Lenzholzer, 2015). Vegetation can spread coolness 100-1000 meter into an urban area and can cool on average 1 - 4,7°C. However, it is very much dependent on the amount of water available for the plant or tree (Kleerekoper et al., 2012). Also grass and flowers influence the temperature and air humidity by evapotranspiration (Lenzholzer & van der Wulp, 2010). Evapotranspiration tempers the temperature because plants convert solar into latent heat (Klemm et al., 2013).

2.4 Conclusions

To make a neighbourhood more ageing-proof and suitable for all age groups, the public space should be accessible. A highly accessible neighbourhood encourages elderly to go out for a walk and this keeps them active and fit. An accessible space for elderly should consist of a safe infrastructure, a well-connected pedestrian network and a legible and clear pedestrian infrastructure. So, to improve the accessibility of public space, it should meet these three criteria:

- Safe infrastructure
- Well-connected pedestrian network
- Legible and clear pedestrian infrastructure

To be able to repel heat stress, the public space should be thermally comfortable. An urban design can improve thermal comfort if it provides shadow, if it cools the microclimate through evaporation and evapotranspiration and if the design minimises the heat accumulation. So, to improve the thermal comfort of public space, it should meet these three criteria:

- Providing shadow
- Minimising heat accumulation
- Cooling by evaporation and evapotranspiration

chapter 3 | methods

3.1 Introduction

In this chapter I will describe which methods I chose to use. Before I could answer the sub research questions and consequential the main research question, I did a preliminary research. This consists of an analysis to identify test beds which will be used in the research through design process that will provide the answers to the research questions. I will discuss which methods I used for the preliminary research and also discuss the results. Then I will describe which methods I used for the research through design process. Figure 6 shows the research process and how the preliminary research serves as a needed basis for the actual research and how this took place.

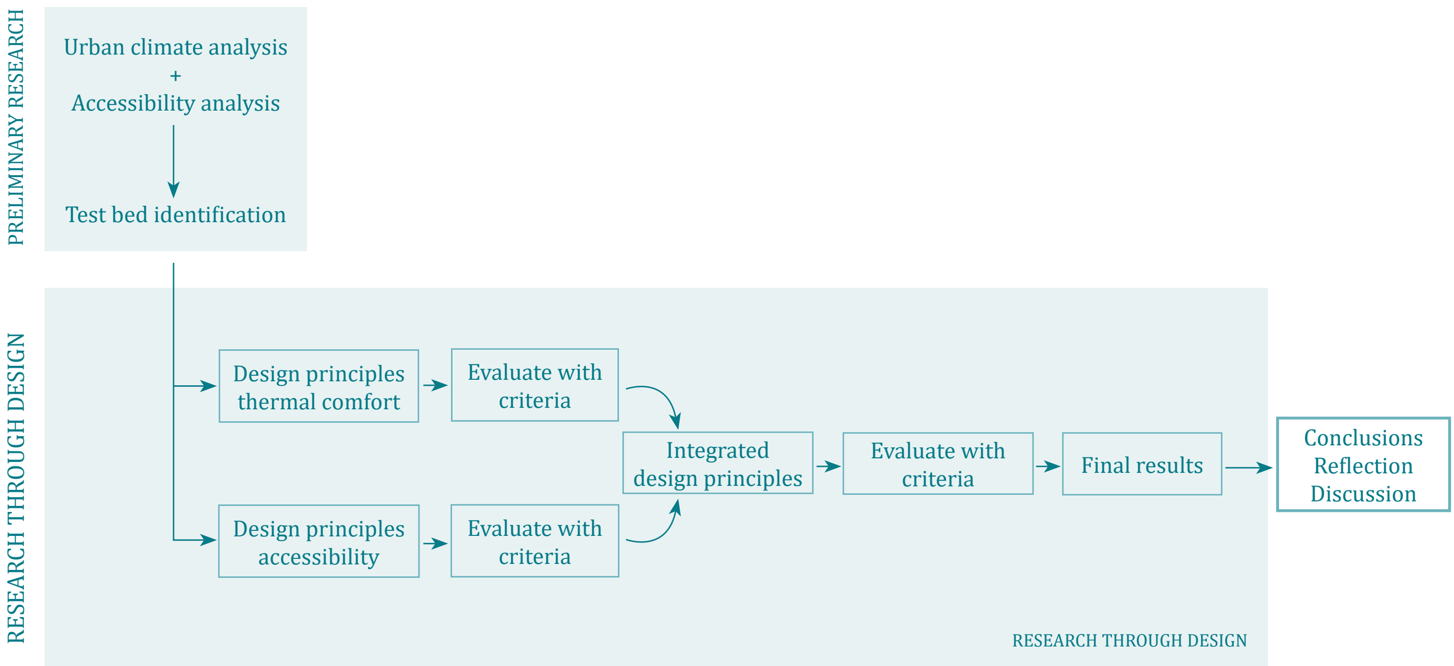


Figure 6. Research process

3.2 Knowledge claim

Landscape architects and urban designers can bring together different wishes and visions in a physical intervention and should be problem solving oriented. They can use different approaches to understand, address and solve problems. This fits the pragmatic worldview, described by Creswell (2014). The problem of this research asks for an integration of knowledge of different aspects: knowledge on the effect of the urban heat island effect on thermal comfort and knowledge on the difficulties elderly have to deal with in outdoor spaces. This asks for a spatial solution, addressed from different points of view.

To answer the research questions, a research through designing process is used. In a research through design process, designing is used as a research method in order to generate new knowledge. This fits the constructivist knowledge claim, because it suggests new constructs (thermal comfort and accessibility in outdoor space) and creates new knowledge (design principles). In a constructivist research, interactions of people with the environment need to be addressed (Lenzholzer, Duchhart & Koh, 2013). The newly generated knowledge should be applicable in design practice, in the form of design principles or guidelines that are general and not site-specific (Lenzholzer, Duchhart & Van den Brink, 2016).

3.3 Preliminary research

3.3.1 Methods for identifying test beds

In order to develop design principles, a research context was needed to identify test beds in which the design principles could be tested. A test bed is a generalised 3D model of an existing situation. The test bed can be derived from an analysis into problematic spatial configurations in a study area. The test beds represent the most problematic and characteristic spatial configurations. Because the design principles will be designed in a generalised model, they will be relevant and useful for all spatial configurations that are similar. This is an added value to the research, because the newly generated knowledge will be applicable in more than one place. In this research, the test bed should be a representation of a residential street, because this is the close living environment of elderly and there the interventions will be most noticeable for them.

Macro scale | The analysis which was needed to come to test beds started on the larger scale of the Netherlands and focused on bigger cities that suffer from the heat island effect. The analysis must indicate in which cities there is a serious problem with the urban heat island and where already research and measurements has been done. Besides that, the analyses should indicate which cities are actively working on establishing an aging-proof society. The analysis is done with a literature study, a map study and an assessment of websites of different municipalities.

Meso scale | When the city was selected, the analysis continued on a smaller scale to select a neighbourhood. The neighbourhood should suffer from heat problems and this was analysed by studying different heat maps and researches. I looked also into researches of the municipality about the inhabitants opinions about the living environments to see if there are neighbourhoods where the people are not satisfied with the outdoor space. In this analysis I also looked into the amounts of elderly and adults who will reach the age of 65 within 20 years in the neighbourhoods.

Micro scale | After the selection of the neighbourhood, the analysis continued on an even smaller scale: the level of the streets. To find the places which could be represented in test beds, a thermal comfort analysis and an accessibility analysis were executed. The thermal comfort analysis was conducted through shadow analyses in a 3D model in SketchUp of the neighbourhood. This analysis found the problematic places in the neighbourhood where there is very little shadow. Since shadow or the lack of shadow is the most sensible measure in thermal comfort, this is a useful way to analyse a neighbourhood without the need for complicated measurement tools. The 3D model consists of the buildings and the trees in the neighbourhood. I used the 21st of June to model the shadows every 15 minutes, because this is the day that the sun is at its highest point and objects cast the smallest amount of shadow. So this is a date that represents the most unfavourable situation in a warm summer. I also did a shadow analysis for the 21st of August, to show the effects of a lower positioned sun and because the city is already warmed up for a while.

To be able to analyse the accessibility, or the lack of accessibility, I analysed where elderly walk. By marking 'anchor points' you can assume which routes are being used. Anchor points are places which are physical recognisable and which have a concentration of services and functions that are appealing to the target group (Höppner et al., 2014). I analysed the anchor points where elderly might go to, such as shops, community centres, religious buildings, parks, medical services like the general practitioner and public transport stops. These places are important in the daily routines of elderly, because they often need a functional reason to leave the house (Höppner & Arnold, 2013). This map with routes was used to make an inventory of all the defects in the streets that contribute to an inaccessible outdoor space. This analysis was done during a site visit and the following components were marked in maps:

Pavement irregular	Sidewalk
Tiles crooked or protruding	Too narrow, less than 1,8m
Missing tiles	A lot of fixed obstacles
Broken tiles	A lot of temporary obstacles
Ramp to curb	Unsafe crossing
No ramp	No zebra
Ramp is too steep	No raised crossing/speed bump
Ramp is too narrow	No traffic islands

The analyses resulted in a map that shows the streets with the worst conditions in terms of shadow and thus have a heat problem, and a map that shows the most inaccessible streets. From these streets, the test beds could be shaped.

3.3.2 Results of test bed identification

Macro scale | Research shows that the Netherlands suffers from urban heat islands in the cities, which can also be seen in figure 7. The cities of Amsterdam, Utrecht, Den Haag and Rotterdam suffer the most. Maximum differences in temperatures between the city and the countryside vary from 1 to 8 ˚C (Gemeentewerken Rotterdam, 2011). This difference in temperature has mainly to do with the characteristics of the urban environment. Buildings and a lot of pavement are absorbing a lot of heat compared to green areas (Döpp, 2011).

I choose to focus on the city of Rotterdam. This has two reasons:
First, in Rotterdam there has been already research and measurements done concerning the heat island effect. There are maps and researches available about the temperature differences and other aspects that affect the urban heat island effect.
Second, the municipality of Rotterdam is working on policy about how to change the city into a more aging-proof society. They are thinking about new ways of how elderly are able to live longer at home with the project 'Langer thuis'. They are aiming for new policies and strategies to cope with the changing health care system and increasing numbers of elderly.

Research shows that Rotterdam suffers from a considerable urban heat island effect in the city centre and its surrounding neighbourhoods which are densely built (Van Hove et al., 2011). During the heat wave in July 2006, 75 more older people died than normally in July which brings the total on 385 elderly (Van der Hoeven & Wandl, 2015). The largest UHI intensity was shown in the city centre, followed by the south and east of Rotterdam (Van Hove et al., 2011). Also the harbours show high temperatures, probably because of the industrial activities. In figure 8, the yellow and light green areas are showing where there are more than ten days each year when the temperature doesn't come below 20°C. Figure 9 shows that the number of days will increase (more orange) in the future scenario W for 2050 of the KNMI (Climate Adaptation Services, 2017).

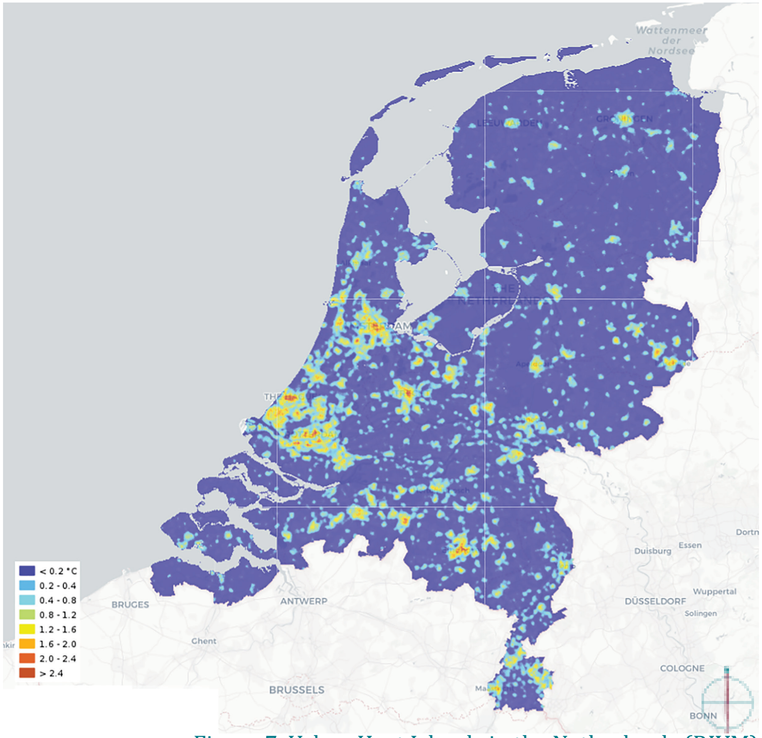


Figure 7. Urban Heat Islands in the Netherlands (RIVM)

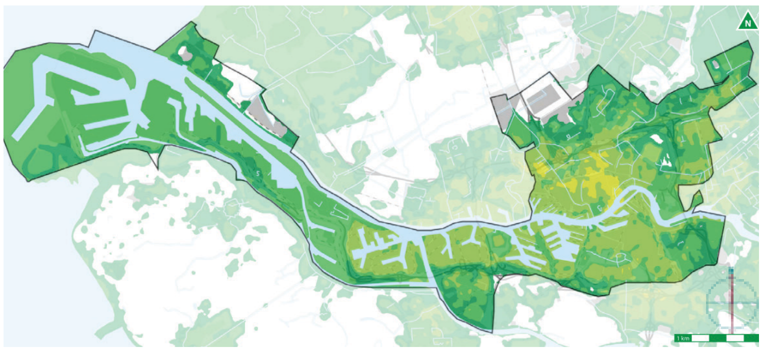


Figure 8. Current Urban Heat Island effect in the municipality of Rotterdam (Climate Adaptation Services, 2017)

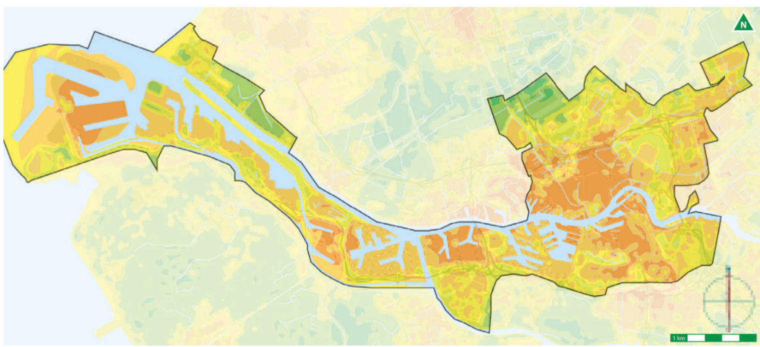
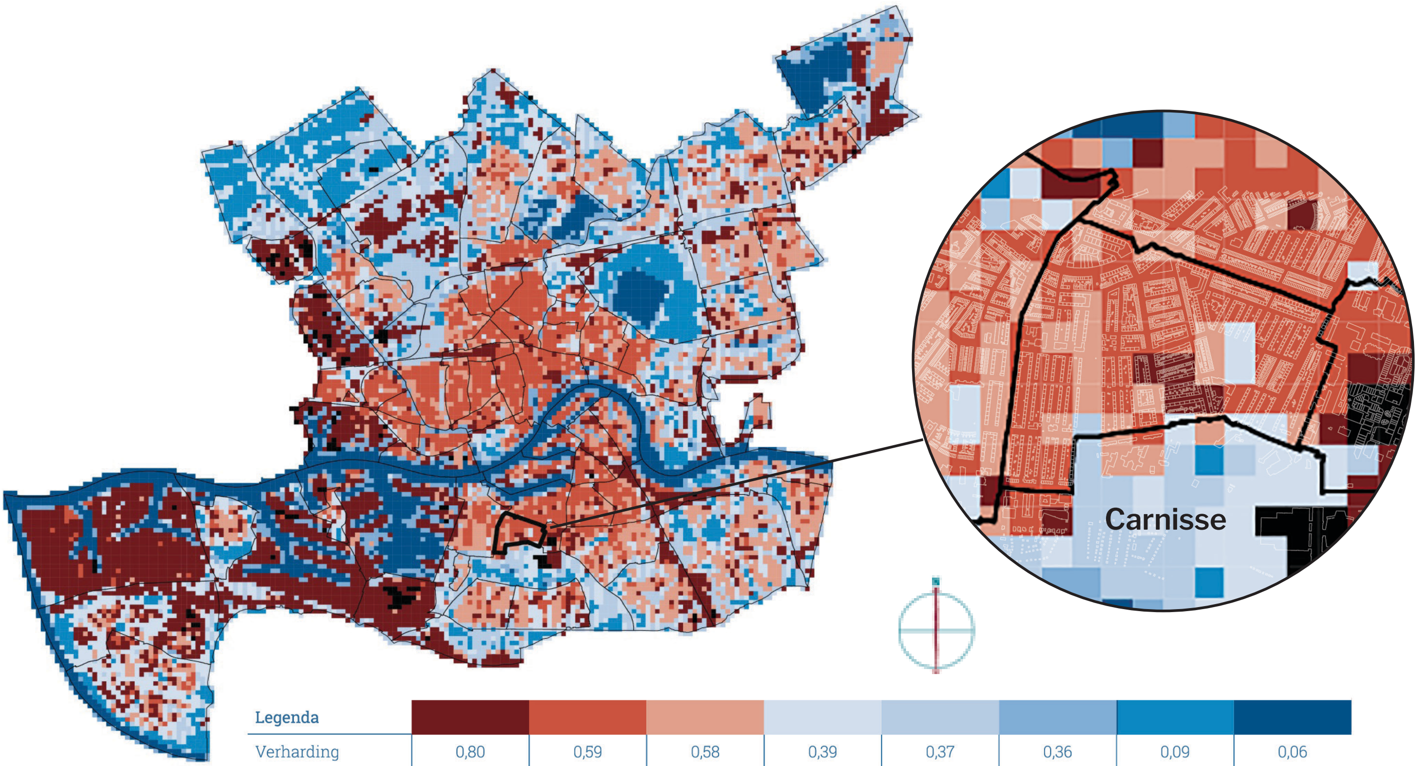


Figure 9. Urban Heat Island effect in scenario 2050W of the KNMI in the municipality of Rotterdam (Climate Adaptation Services, 2017)



Legenda								
Verharding	0,80	0,59	0,58	0,39	0,37	0,36	0,09	0,06
Gebladerte (LAI)	249	350	557	1014	1056	262	2074	27
Gebouwschil	1261 m^2/ha	8136 m^2/ha	4269 m^2/ha	1139 m^2/ha	663 m^2/ha	732 m^2/ha	136 m^2/ha	23 m^2/ha
Oppervlaktewater	3%	2%	4%	7%	8%	54%	8%	96%
Schaduw	2,4	2,8	3,9	1,4	4,5	2,9	2,8	2,5
QH + QS	456 W/m^2	406 W/m^2	375 W/m^2	324 W/m^2	316 W/m^2	311 W/m^2	242 W/m^2	119 W/m^2

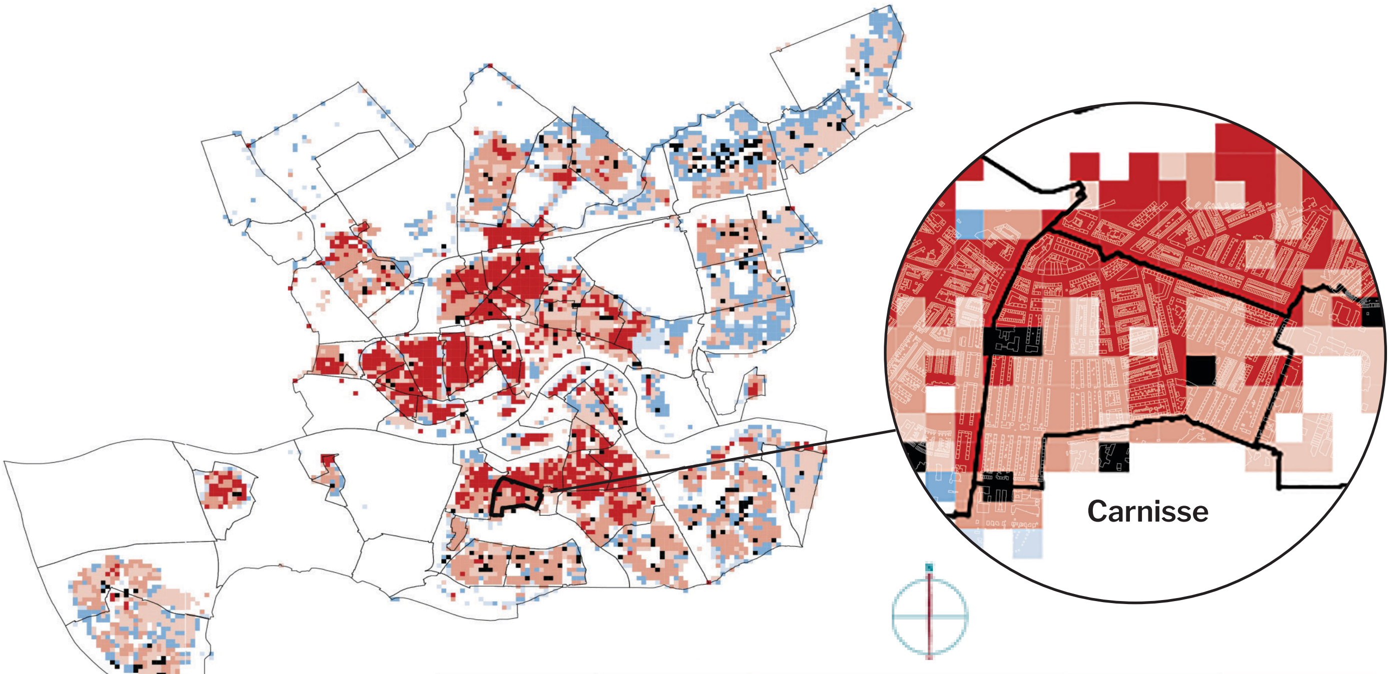
Figure 10. Physical heat map (van der Hoeven & Wandl, 2015)

Meso scale | In selecting which neighbourhood in Rotterdam should be used for identifying test beds, I looked into the research of Van der Hoeven and Wandl (2015). They researched the urban heat island effect in Rotterdam and how it relates to the physical spatial configuration and to the socio-economic characteristics.
In the meanwhile, there was a design contest launched, called 'Who Cares?'. This design contest was initiated by the architectural government adviser and takes place in four neighbourhoods across the Netherlands. One of them is the neighbourhood of Carnisse in Rotterdam. The contest asked for creative ideas about how to organise new forms of living environments and health care for elderly in the future. Carnisse turned out to be an interesting neighbourhood because of the age of the buildings (some pre-war, but mostly post-war) and the poor state of the public space. I will come back to this later this chapter.

Urban heat island

Regarding the research of Van der Hoeven and Wandl (2015), the neighbourhood I select should be located in the city centre or its surrounding neighbourhoods. Carnisse is located south of the city centre and suffers from heat problems. We can see this in the two maps (fig. 10 & 11) from Van der Hoeven and Wandl (2015). Figure 10 shows the physical heat map of Rotterdam. The dark red areas are the warmest, followed by the orange. It shows that the neighbourhood Carnisse (marked with black line) mostly has the orange colour. This means that there is a high amount of sensible heat and heat storage, and that there is a big surface of built area. In figure 11, the social heat map, we can see how the urban heat island effect is related to social factors such as how many people of 75 years or older live there per hectare, how old the buildings are and how much sensible heat and heat storage is measured. Carnisse is mainly red and pink coloured. The red areas have the highest amount of storage heat and sensible heat and the buildings in this area are 85 years old on average. The pink area has slightly less storage heat and sensible heat, and the buildings are 59 years old on average. There are also some places with the black colour, these are places where a lot of elderly are living concentrated in flats.

According to the research of Rovers et al. (2014) the amount of days with moderate to strong heat stress will increase, especially in Rotterdam South. The research of Heusinkveld et al. (2014) shows measurements of the Urban Heat Island effect in Rotterdam, this can be seen in figure 13. The measuring point 'South' is located next to Carnisse.
Most areas in Carnisse suffer from more than 400 W/m^2 of sensible heat and heat storage in buildings, soil and surface water. Also the amount of vegetation is very low and the paved surface is very large. Only 1% of the surface consists of water and only 7% is green area, of which 5% is public green. The rest of the neighbourhood



Legenda						
75-plussers/ha	77	4	5	4	1	2
Ouderdom gebouw	36 jaar	85 jaar	59 jaar	27 jaar	88 jaar	23 jaar
QH + QS	363 W/m²	411 W/m²	353 W/m²	396 W/m²	294 W/m²	314 W/m²

Figure 11. Social heat map (van der Hoeven & Wandl, 2015)

is built or paved (Klok et al., 2010).

Research shows that 47% of the people in Carnisse think that there are not enough places in the garden or the neighbourhood to cool down under warm circumstances. Besides that, 52% of the people in Carnisse think their house hasn't sufficient cooling during warm periods. This is by far the biggest group of inhabitants within Rotterdam who thinks there are not enough places to find coolness (GGD Rotterdam-Rijnmond, 2017).

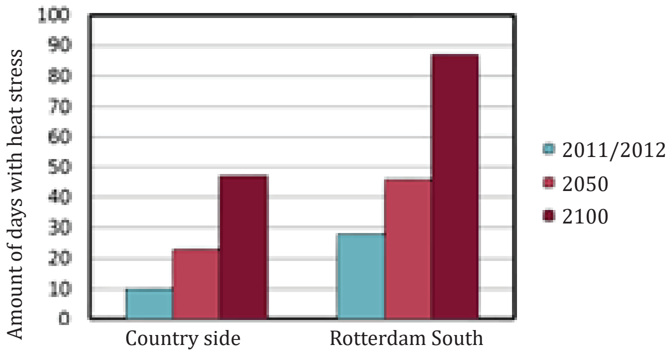


Figure 12. The amount of days with moderate to strong heat stress (Rovers et al., 2014)

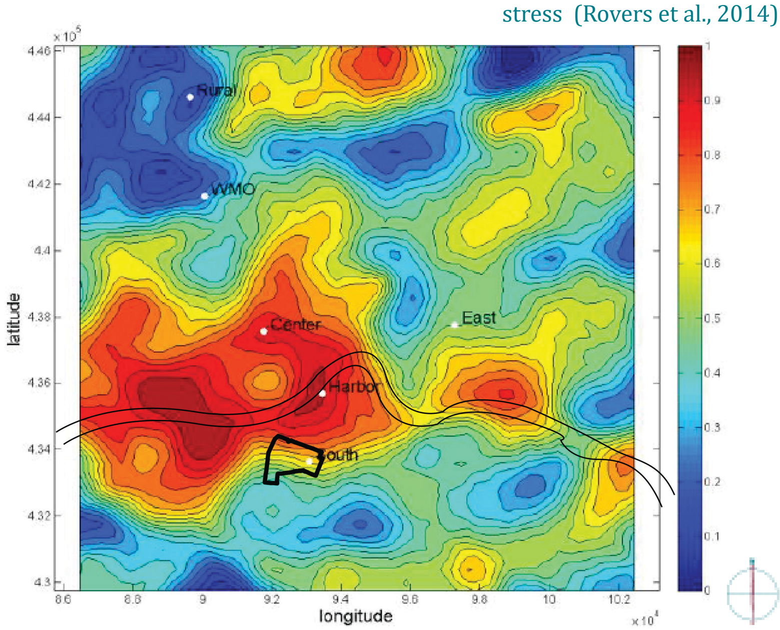


Figure 13. Measurements of the Urban Heat Island Effect in Rotterdam (Heusinkveld et al., 2014)

Figure 14. Typical street in the neighbourhood Carnisse.

Living environment

Carnisse is very densely populated (Gemeente Rotterdam, 2016b). Approximately 70% of the households consist of one or two persons and 25% consist of families (Gemeente Rotterdam, 2014). Compared to other neighbourhoods, there live little amounts of children (Gemeente Rotterdam, 2017). 9% of the people in Carnisse is 65 years or older (Gemeente Rotterdam, 2016), but almost 20% is between 45 and 65 years old (CBS, 2015). Almost one third of the elderly live in nursing homes from Laurens and Humanitas (Gemeente Rotterdam, 2017).

In general, the people in Carnisse are not satisfied with their living experience as you can see in the chart (figure 15). This chart shows that they do not live pleasantly in Carnisse and tend to move away fast. Compared to the average in Rotterdam, Carnisse is staying behind in general on physical, social and safety index. The outdoor public space is rated lower than average. This has to do with the dissatisfaction about how clean the neighbourhood is, how well maintained (the pavement and street furniture), the quantity and quality of public green spaces and traffic safety. Only 50% of the people in Carnisse are in contact with their neighbours. The social binding is very low, people do not feel connected with the neighbourhood or the city Rotterdam. 55% of the people older than 65 in Carnisse feel socially lonely (GGD Rotterdam-Rijnmond, 2017).

Health

The average health of people in Carnisse is bad: figures show that the health of people in Carnisse is worse than average in Rotterdam and the Netherlands. Their life expectancy is lower than the average of the Netherlands (see figure 19) (CBS, 2016; GGD Rotterdam-Rijnmond, 2017). 41% of the people in Carnisse older than 65 years does not meet the movement standard, so they don't exercise enough. 67% of the people older than 65 years have overweight and even 20% has obesity (GGD Rotterdam-Rijnmond, 2017).

34% of the people older than 65 years fell down last year and 27% is limited to take care of their own household. 36% of the elderly in Carnisse are having trouble with their ears, eyes or mobility (GGD Rotterdam-Rijnmond, 2017).

Fact sheet Carnisse

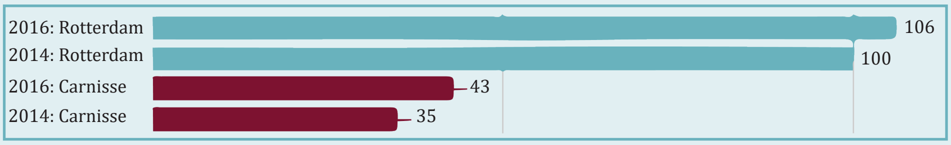


Figure 15. Rating living experience (GGD-Rotterdam Rijnmond, 2017).

Figure 16. Low social binding in Carnisse (GGD Rotterdam-Rijnmond, 2017).

NDVI	0,39
Built (%)	30
Water (%)	1
Public green (%)	5
Building height (m)	10
Total green (%)	7
Total paved (%)	92
Population density (ha-1)	175
Albedo	0,09
Emissivity	0,96
Skyview factor	0,62
Topp (°C)	28,3

Figure 17. Land use index of Carnisse (Klok et al., 2010).

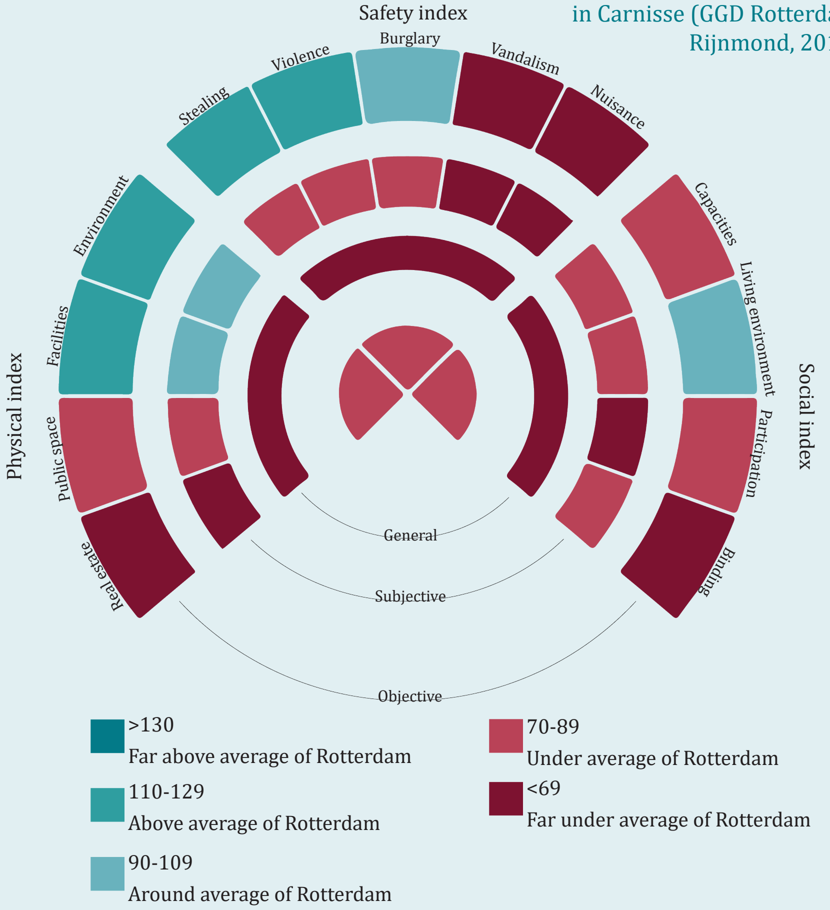


Figure 18. Neighbourhood profile of Carnisse (GGD Rotterdam-Rijnmond, 2017).

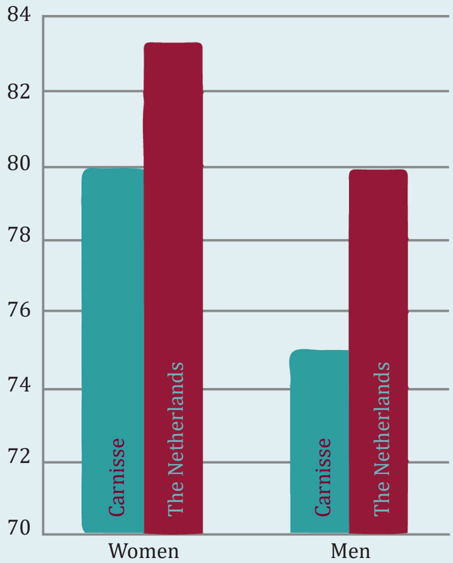


Figure 19. Life expectancy of people in Carnisse compared to people in the Netherlands (CBS, 2016; GGD Rotterdam-Rijnmond, 2017).

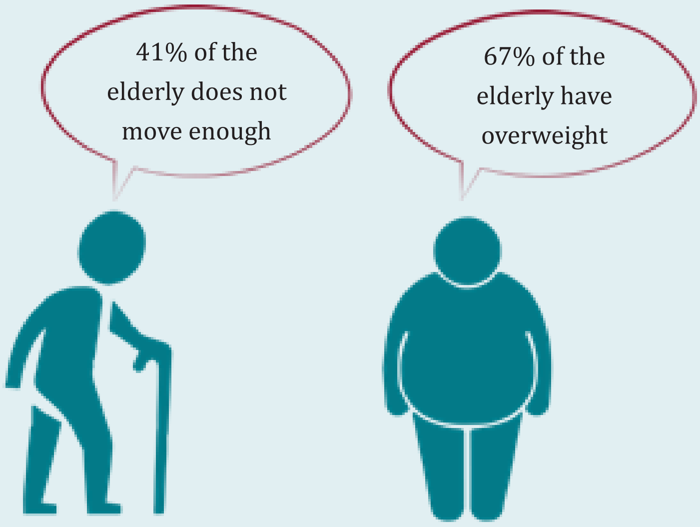


Figure 20. Elderly are not meeting the movement standard and a big amount is having overweight (GGD Rotterdam-Rijnmond, 2017).

Figure 21. 3D model of Carnisse in SketchUp

Micro scale | A shadow and accessibility analysis should result in an overview of the most problematic streets in Carnisse which will be used for forming test beds.

Shadow analysis

A 3D model of Carnisse was built in SketchUp with all buildings and trees (figure 21). With an automated shadow simulation, a map was created which shows the sum of hours of shadow during the day. The analysis of June 21st shows that mainly the streets that are oriented in West-East direction (or nearly West-East) are exposed to a lot of sun. Some parts of these streets do not have any shadow during the day. As can be seen in figure 22, most streets that are oriented North-South do have shadow, mostly 4 to 6 hours a day. On August 21st there is overall more shadow in all streets, because the sun is at a lower position. However, some West-East oriented streets still have little shadow. The North-South oriented streets have more shadow, mostly 4 to 8 hours per day.

Another shadow analysis was done by simulating shadow separately for each hour of the day, to be able to see which streets are most exposed to the sun at the hottest moment of the day (between 12:00AM and 16:00PM). On page 42 in figure 23 you can see the shadows in Carnisse for each hour on June 21st. It shows that around 11:00AM there is some shadow in the North-South oriented streets. Around 12:00AM and 13:00PM there is almost no shadow in Carnisse. Around 14:00PM and 15:00PM there is partially shadow in the North-South oriented streets. From 16:00PM these streets are totally covered with shadow. However, the West-East oriented streets start to have shadow only after 17:00PM. The rest of the day these streets are exposed to the sun.

We can conclude that mainly the West-East oriented streets in Carnisse are very much exposed to the sun. They have almost no shadow at the hottest moments of the day. The North-South oriented streets have more shadow, but have a height/width-ratio that is less desirable and is probably retaining more heat. The West-East streets would mostly need interventions that provide shadow.

Especially the street 'Meester Arendstraat' is very exposed to the sun during the day. This street is West-East oriented and representing several streets in the neighbourhood with a similar lay-out and height-width ratio. It is also a street where there is a lot of pavement and which is used as walking route between facilities.

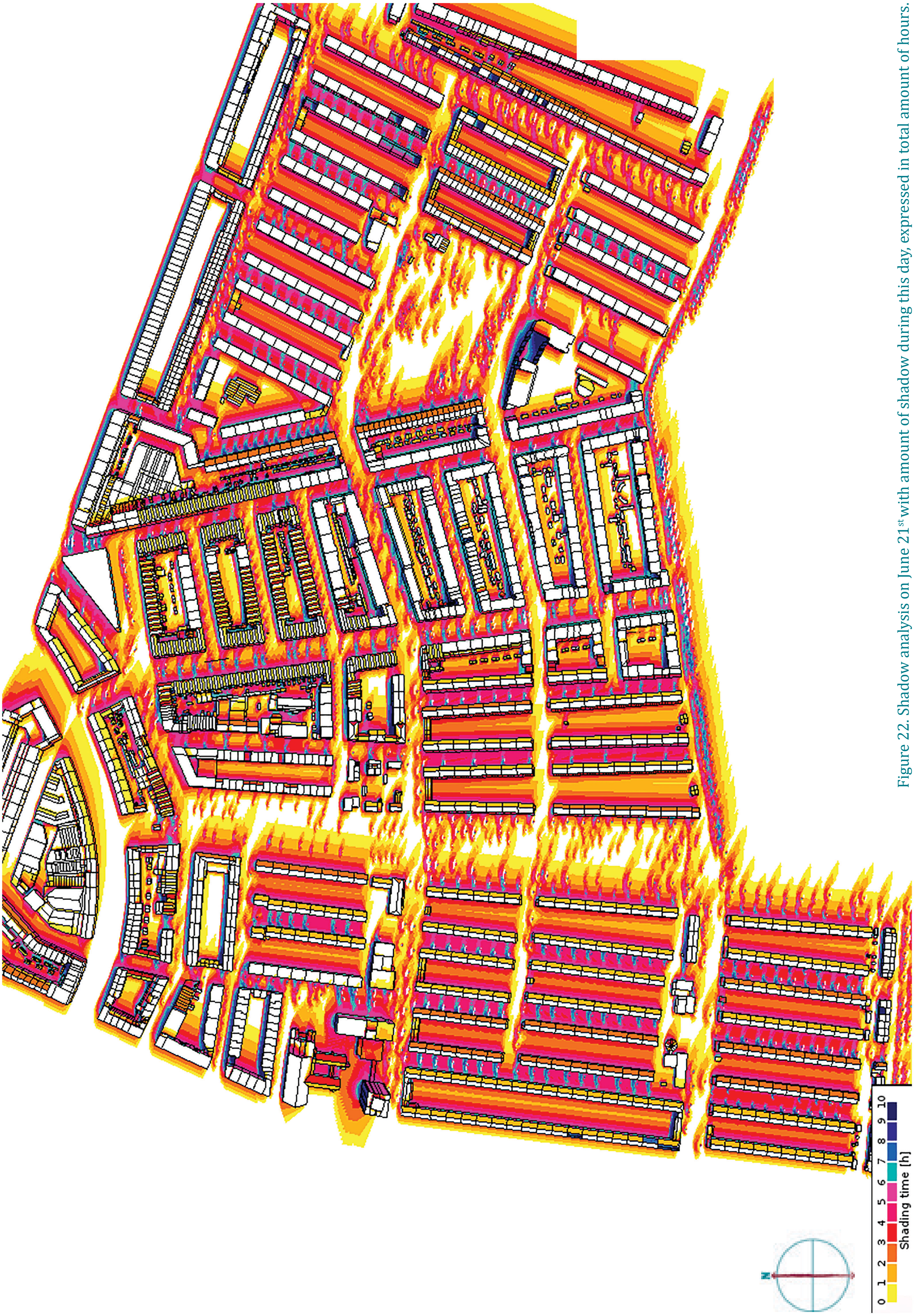


Figure 22. Shadow analysis on June 21st with amount of shadow during this day, expressed in total amount of hours.

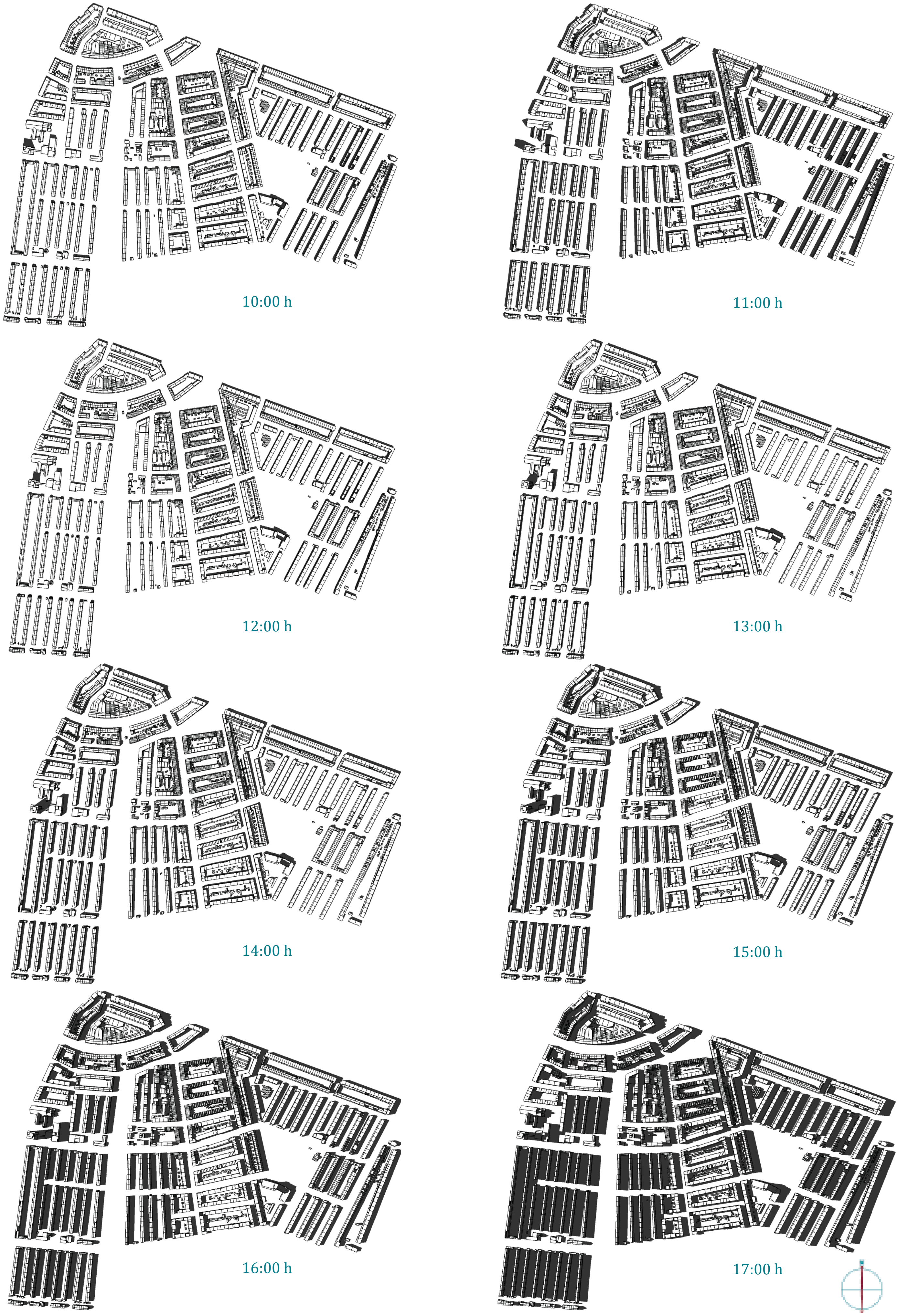


Figure 23. Shadows at the 21st of June

Accessibility analysis

All facilities or 'anchor points' in Carnisse were mapped. As can be seen in figure 26 on the next page, many functions are very spread throughout the neighbourhood. For elderly, primary services and facilities should be within 500 meter of their homes and secondary services should be within 800 meter (Burton & Mitchell, 2006). The big shopping mall Zuidplein, on the East of Carnisse, is close by, but in Carnisse there are some shops as well. The map shows (figure 25) the reach of elderly from the four elderly homes is covering almost the whole neighbourhood. Only the people of the purple and red buildings are not reaching the shopping mall Zuidplein. These people are designated to the small shops in Carnisse or can take the public transport.

All possible routes between the facilities were mapped. On these routes there was an inventory made of all the places that lack accessibility or have any defects in the pedestrian infrastructure. Figure 24 shows some examples. The streets with the most defects are interesting places to maybe use as test bed. The defects are categorised and marked in a map. The following aspects were noted:

- Pavement irregular: tiles crooked or protruding, missing tiles, broken tiles,
- Unsafe crossing: no zebra, no raised crossing/speed bump, no traffic island
- Sidewalk: too narrow - less than 1.8m, a lot of fixed obstacles, a lot of temporary obstacles
- Ramp to <u>curb</u>: no ramp, ramp is too steep, ramp is too narrow

This inventory lead to the following map (figure 27), which shows all the defects in accessibility and which streets are the least accessible.

The 'Gruttostraat' is scoring lowest in the amount of accessibility, while there are a lot of facilities elderly could visit. There is also an elderly home located in this street. It is also a busy road full of traffic, so a safe pedestrian infrastructure is desirable.

Very full and messy sidewalk.

Very narrow sidewalk because of the sign.

No lowered curb which makes it harder to crosse the street at this point.

Sidewalk gets very full and narrow with parked bicycles, sign, letter box and garbage bin.

Raised crossing blocked by a tree.

Gates block the passage for people with rollators or wheelchairs.

Loose and crooked tiles.

Missing and crooked tiles because of a tree hole.

Figure 24. Inventory of defects in Carnisse

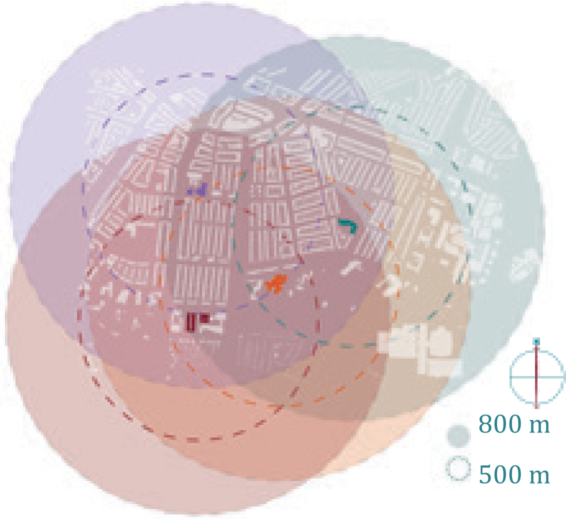


Figure 25. The reach of elderly from the four elderly homes in Carnisse

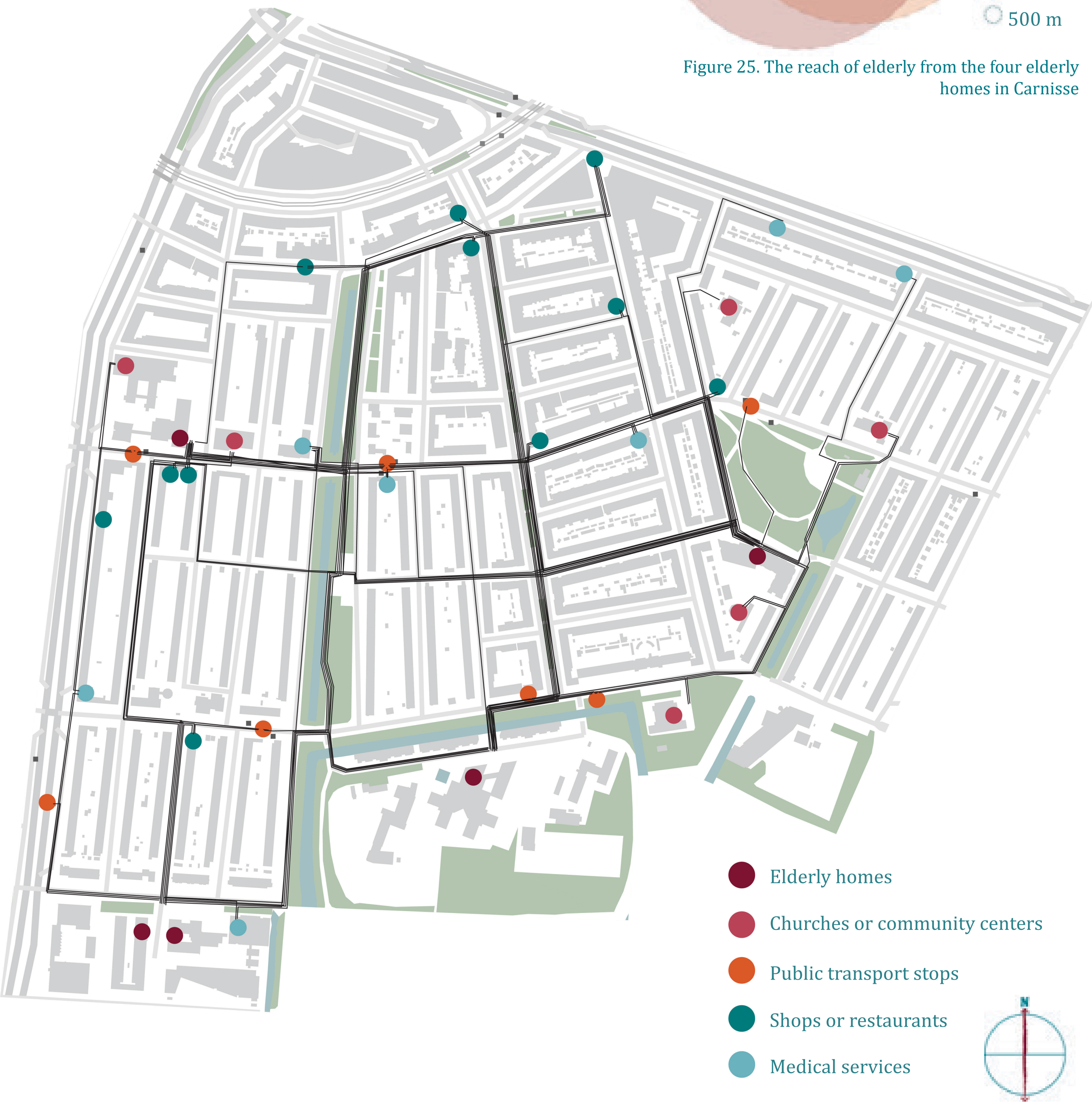


Figure 26. Routes to facilities

Figure 27. Amount of inaccessibility

Conclusions

As can be seen in the two maps (fig 28 and 31), the analyses show that the street with the least thermal comfort does not correspond with the street with the least accessibility. Therefore I decided to construct two different test beds to design the principles. One test bed is based on the Gruttostraat and will be used to design principles to improve the accessibility for elderly. The other test bed is based on the Meester Arendstraat and will be used to design principles to improve thermal comfort. These test beds are generalised 3D models and look like figure 30 and 33.

Thermal comfort

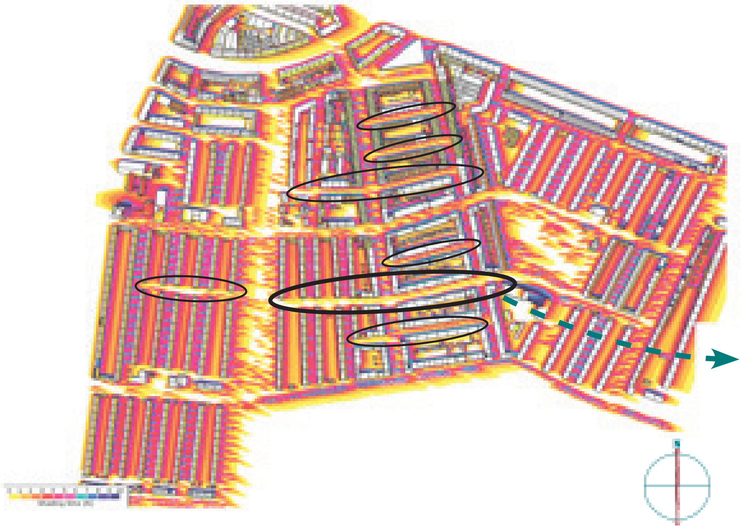


Figure 28. The shadow analysis shows the streets that have not much shadow and therefore are not thermally comfortable.

Figure 29. Meester Arendstraat

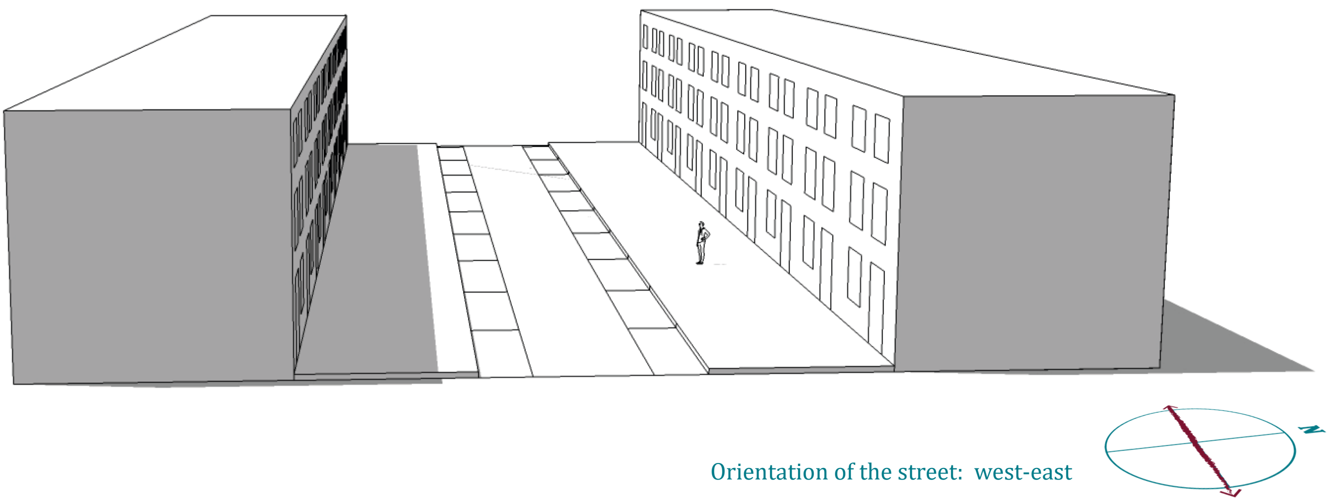


Figure 30. The test bed for design principles to improve thermal comfort.

Accessibility

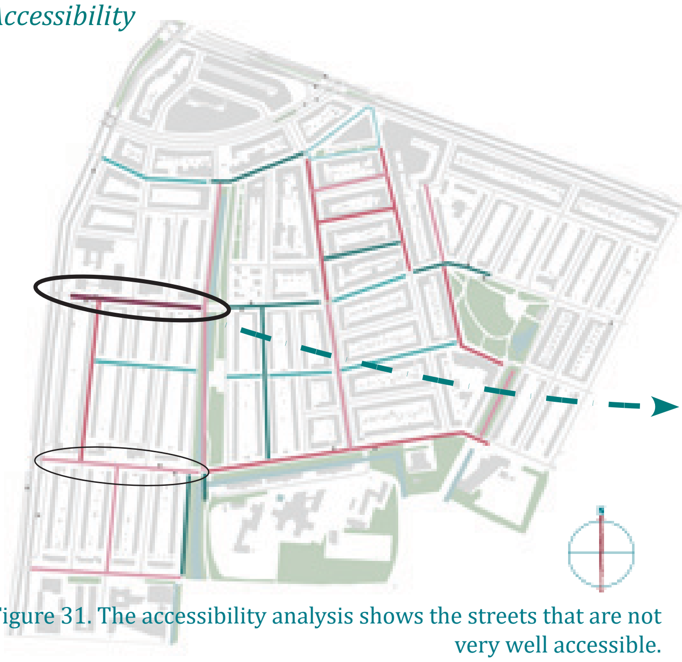


Figure 31. The accessibility analysis shows the streets that are not very well accessible.

Figure 32. Gruttostraat

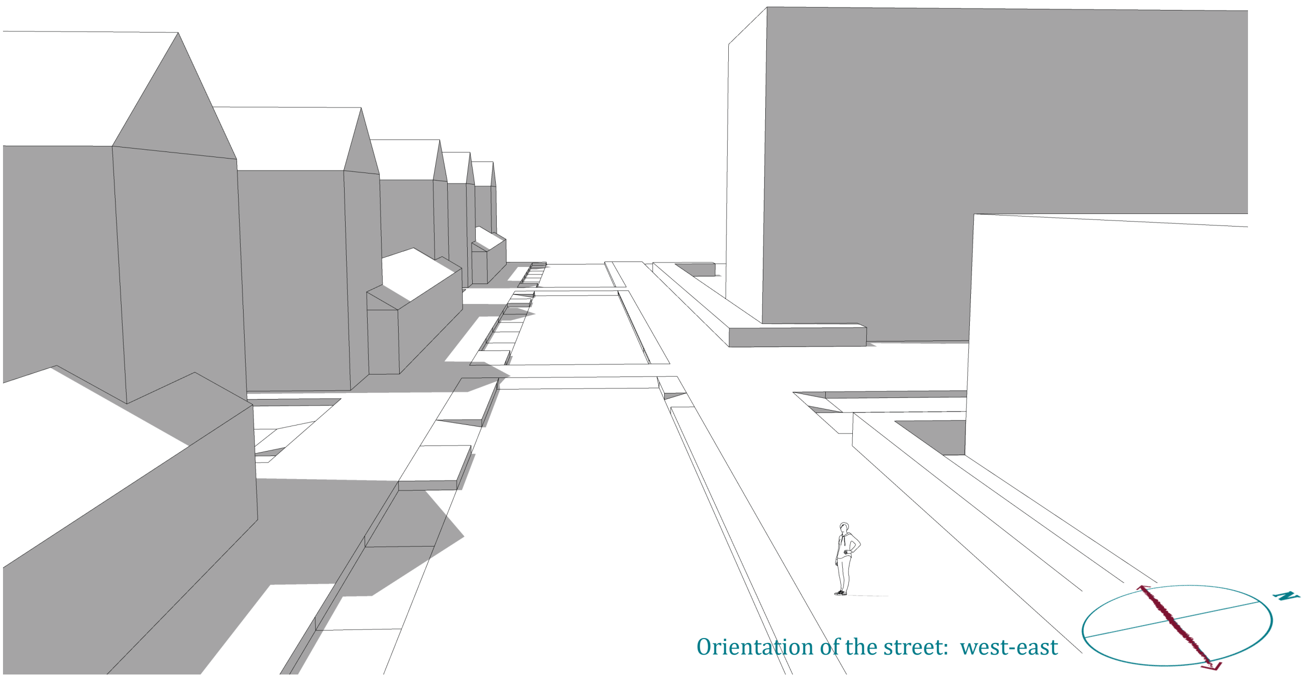


Figure 33. The test bed for design principles to improve accessibility.

3.4 Research through design

3.4.1 Introduction
In the preliminary research the test beds were identified. These were used in the research through design process to develop design principles in order to answer the sub research questions.

3.4.2 Answering the sub research questions
To answer the two sub research questions

SRQ1: *'what design principles make a street thermally comfortable?'*
and SRQ2: *'what design principles make a street accessible for elderly?'*

a research through design process was used. By an iterative process of designing and testing these design principles in the test beds, knowledge on what would work and what would not work was derived. The design process started by making an extensive inventory of all possible design solutions for both thermal comfort and accessibility for elderly. This inventory was based on a study into existing designs and plans, literature and websites, but was also based on the creativity of the researcher. All design solutions were tested during sketch sessions in all possible ways. For instance if it would fit to place one, two or even three rows of trees in the test bed. Or what were all possible ways to make a crossing more safe. During this process, a selection was made of the solutions that were best suitable for the test beds. The decisions were made on how feasible the solutions were and if it would fit in these test beds. This designing and testing process delivered the final design principles as answers to the sub research questions.

3.4.3 Evaluating the design principles with criteria
From the theoretical framework criteria were derived with which the design principles must comply. By evaluating the design principles according to the criteria, it became clear which design principles are best to use in the next phase of the research through design process. Some design principles could be eliminated according to this evaluation, because they scored too low.
The design principles for thermal comfort will be assessed according to the criteria concerning thermal comfort. The design principles for accessibility for elderly will be assessed according to the criteria concerning accessibility for elderly. Each design principle was evaluated for each criterion with a grading system from 0 to 10 points. 0 points means that the design principle is not meeting the criterion at all. Scoring 10 points means that the design principle fulfils the criterion and is a very good solution. This evaluation with grades was done by comparing the design principles with each other. If the design principles were scored on for instance 'providing shadow', the one with the largest amount of shadow was scored the highest and the one with the least amount of shadow was scored lowest. This happened for all criteria and all design principles.

Weighing the criteria
The criteria needed to have a certain weighing. Some criteria are more important or relevant than others. This has to do with the expected effect. However, some criteria could also be weighed the same if they were equally important. Further study into literature resulted in a weighing of the three criteria per type of design principles.

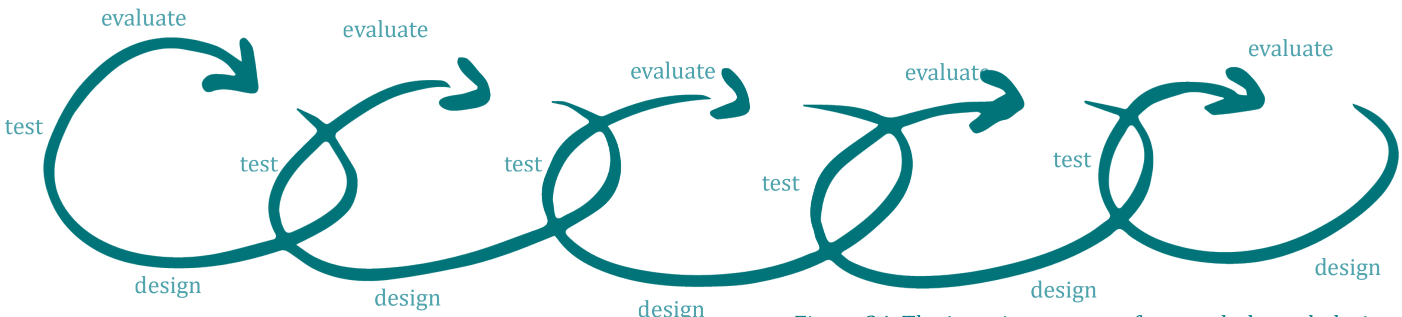


Figure 34. The iterative process of research through design.

Thermal comfort

The criteria with which the design principles for thermal comfort must comply are:

- Providing shadow
- Minimise heat accumulation
- Cooling by evaporation and evapotranspiration

The criterion of providing shadow was weighed the heaviest, because the presence, or absence, of shortwave solar radiation is what people experience the most (Brown et al., 2015; Lenzholzer, 2015). The direct radiation of the sun makes a sunny spot feel much warmer than a shaded spot. A sunny spot in Central Europe will receive at least 1000 Watt per square meter at noon, while this spot only receives 500 Watt per square meter when it is a cloudy day. The shadow of a building is even minimising this to only 100 Watt per square meter (Lenzholzer, 2015).

The criterion of minimising heat accumulation was weighed as second, because the reflectivity (albedo), the emissivity and the conductivity of materials are crucial for the heat storage. After direct shortwave solar radiation, longwave radiation is felt by emitting heat even when the air temperature has come down. Minimising heat accumulation is therefore of big influence of the thermoregulation in cities (Lenzholzer, 2015).

The criterion for cooling through evaporation and evapotranspiration was weighed the lowest, because this is especially influencing the urban climate at a bigger scale and is less sensible for pedestrians in the street (Lenzholzer, 2015).

To conclude, the criteria will be weighed the following:

Provide shadow	50%
Minimise heat accumulation	30%
Cooling by evaporation and evapotranspiration	20%
Total score	100%

Accessibility

The criteria with which the design principles for accessibility for elderly must comply are:

- Safety: safe infrastructure
- Connectivity: pedestrian network well connected
- Legibility: legible and clear pedestrian infrastructure

The criterion for a safe infrastructure was weighed the heaviest because this will be the most crucial for elderly when they decide whether they will go out for a walk or not. Safety is more important than for instance minimising the distance to a destination (Michael et al., 2006). A safe infrastructure is also very important to protect elderly from any harm. Research shows that there is a connection between the quality of sidewalks and if people move away from the neighbourhood (Van Staalduinen, 2014). There is also evidence that safety is positively related to more leisure-time physical activity (Rydin et al., 2012).

The criteria of a well-connected network and legibility were weighed the same. When destinations are not easily reached and there is no choice of routes, elderly will choose to stay home or have to rely on other forms of transport. A high connectivity will increase overall physical activity (Pearce & Maddison, 2011). Literature is not so clear about how big the influence of the presence of legibility is. However, we know that approximately one third of the older population has some form of physical disability (RIVM, 2011). These people have more trouble finding their way through the neighbourhood and the absence of a legible and clear pedestrian infrastructure will negatively influence this.

To conclude, the criteria will be weighed the following:

Safety	50%
Connectivity	25%
Legibility	25%
Total score	100%

3.4.4 Constructing a new test bed

With the development of the two types of design principles, two different test beds were used. However, to be able to design new integrated design principles, only one test bed was needed. This would make it easier to compare the different outcomes with each other. The new test bed should represent a residential street, because the main research question is: *What design principles can be developed to improve thermal comfort and accessibility for elderly in residential streets?*.

I decided that the new test should be mainly a representation of a typical residential street and therefore I used the proportions and orientation of the test bed I used for the thermal comfort design principles. However, to make it also more relevant for the accessibility for elderly I included an element from the other test bed: a crossing. Figure 35 shows the new test bed.

3.4.5 Answering the main research question

The previous phase of the research through design process resulted in two types of design principles and an evaluation of them. This evaluation with criteria resulted in a ranking list of the design principles and the three scoring lowest of each type were eliminated. With the design principles that were left, the next phase of the research through design process was started. This first consisted of a sketching session with one design principle of each type (one of thermal comfort and one of accessibility for elderly), where was tested how they would fit along in the new test bed. This was several times mixed in different compositions. Then it was tested what would happen if you add one, two or even more design principles to this. During this process, a selection was made that was best suitable for the test bed. This designing and testing process delivered seven final integrated design principles.

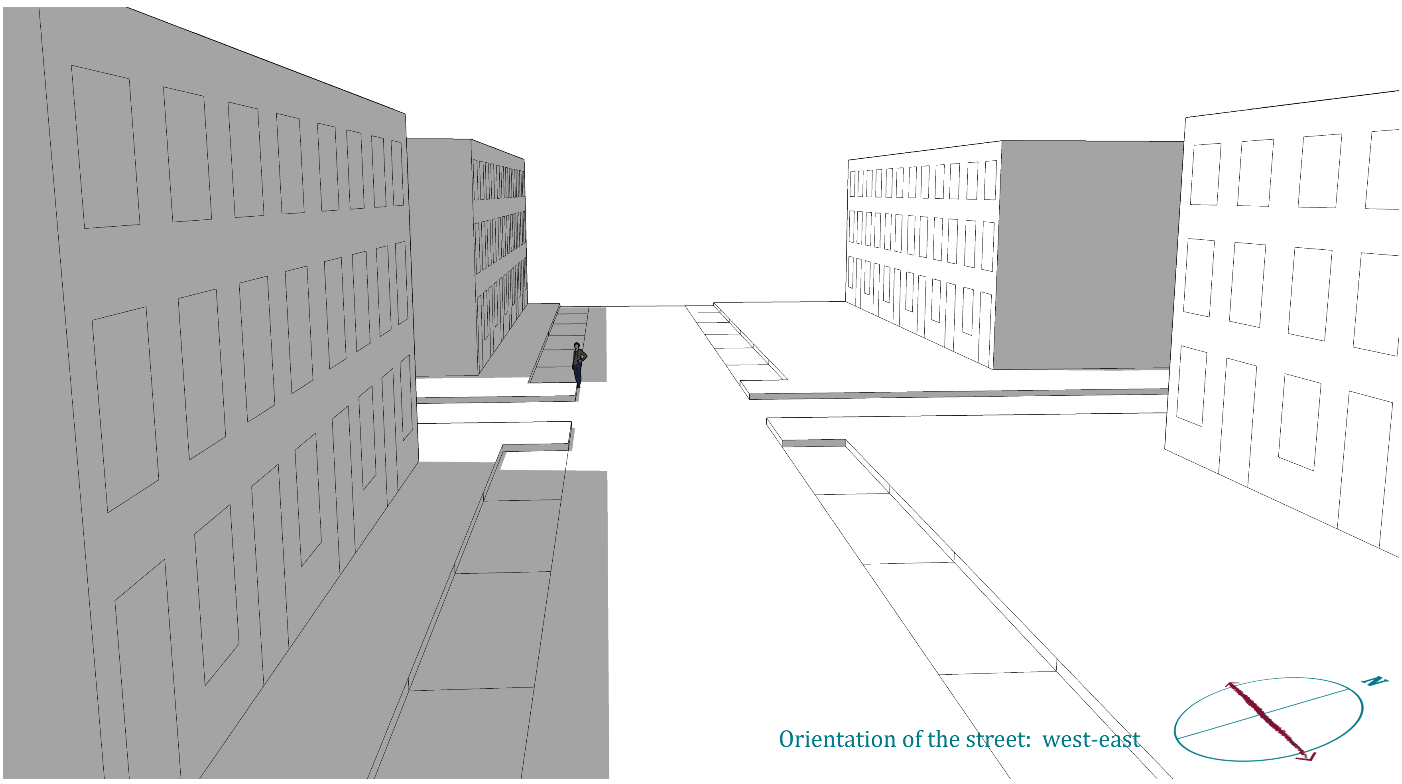


Figure 35. The test bed that will be used to develop integrated design principles.

3.4.6 Evaluating the integrated design principles with criteria

After the research through design phase of integrating design principles, the new integrated design principles were evaluated according to all previous criteria including some more general criteria. These other criteria were meant to assess whether the design is realistic or not. All six criteria from the previous phase were used again:
- Provide shadow
- Minimise heat accumulation
- Cooling by evaporation and evapotranspiration
- Safety
- Connectivity
- Legibility

Besides that, there were four extra criteria taken into account that represent more general aspects in designing:
- Construction costs. If the design principle scores very low on this criterion, it costs a lot of money to construct this design. If it scores high, then it is more appealing because the costs are lower.
- Maintenance. This says something about if this solution needs very regular maintenance or not, and thus costs a lot of money after the construction. If the design principle scores high on this criterion, then it means that there is only a small amount of maintenance needed. If it scores low, then the solution is expensive and labour-intensive.
- Feasibility. This says something about how realistic the solution is. A high score means an achievable solution.
- Seasonality. A design must function well in every season, not only in summer. If the design principle scores high on this criterion, then this solution is suitable for every season.

All 10 criteria were taken into account when evaluating the integrated design principles. On all criteria a grade between 1 and 10 was given, where 10 is a good score and 1 a bad score. The criteria needed to be weighed which are more important than others. Since the main research question is about thermal comfort and accessibility, the six criteria that represent this weighed more than the criteria for general design aspects. I decided they each should weigh twice as much as the general design criteria. Therefore, the three criteria of thermal comfort were weighed for 40% and the three criteria for accessibility were also weighed for 40%. Within this 40%, the three criteria weighed the same as they weighed in the previous evaluation phase of the separate design principles. There was 20% left for the other general design criteria. The criteria will be weighed the following:

Provide shadow	40%	20%
Minimise heat accumulation		12%
Cooling by evaporation and evapotranspiration		8%
Safety	40%	20%
Connectivity		10%
Legibility		10%
Construction costs	20%	5%
Maintenance		5%
Feasibility		5%
Seasonality		5%
Total score	100%	100%

The evaluation with grades was done by comparing the design principles with each other. If the design principles were scored on for instance ‘maintenance’, the one with the least amount of maintenance needed scored the highest and the one with the biggest amount of maintenance needed scored lowest. This happened for all criteria and all design principles.

3.4.7 Results

The evaluation of the integrated design principles resulted in a ranking list. Since the scores were close to each other, there could not be said that there was one clear design principle that stood out. Therefore the best three were considered as the final results and conclusions were drawn from them.


CHAPPEN

chapter 4 | design principles

4.1 Introduction

Chapter 2 identified the criteria with which the design principles must comply. These criteria will be used to evaluate the design principles. Chapter 3.3 resulted in two test beds which are used to explore and test possible design solutions. This chapter shows the result of the research through design process and will be the answer to the two sub-research questions:
SRQ1: What design principles make a street thermally comfortable?
SRQ2: What design principles make a street accessible for elderly?

The design principles in this chapter are a result of an iterative process of designing and testing, which resulted in two types of principles: 10 design principles for improving thermal comfort and 11 design principles for improving the accessibility of residential streets for elderly.

In the coming subchapters, each design principle will be discussed and evaluated according to the criteria which are identified in the theoretical framework. This will result in a selection of the best design principles, which will be used in the next phase of the research through design process: designing the integrated design principles.

With every design principles there is a table in which each criterion is scored.

For thermal comfort the criteria are:

Providing shadow

Minimise heat accumulation

Cooling by evaporation and evapotranspiration

For accessibility for elderly the criteria are:

Safety: safe infrastructure

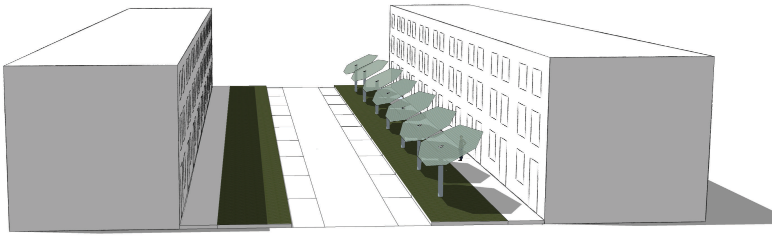
Connectivity: pedestrian network well connected

Legibility: legible and clear pedestrian infrastructure

4.2 Designing and evaluating principles for thermal comfort

I: Moveable shadow screens

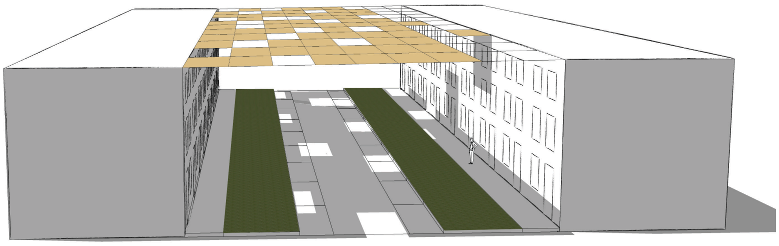
The moveable shadow screens can be moved into the position where it is most profitable for providing shadow. The screens should be placed on the north side of the street, to provide the most sunny sidewalk with shadow. The screens can be turned during the day, following the position of the sun. The screens can also be tilted in another angle. This is very useful since the sun has a different angle each season.
Evaluation: the moveable screens score high on the criterion of providing shadow, because they can cast a shade exactly where it is needed. However, the provided shadow is very local so to cover a whole street with shadow there are numerous screens needed. At the shaded places, less heat accumulation occurs because solar radiation is blocked and cannot be absorbed. However, the screens itself will absorb heat. This solution is not providing any coolness through evaporation or evapotranspiration.



I: moveable shadow screens		
Provide shadow	50%	8*5=40
Minimise heat accumulation	30%	6*3=18
Cooling by evaporation and evapotranspiration	20%	0
Total score	100%	58

II: Moveable shadow shutters

The moveable shutters are hanging above the street and can be closed at moments the sun is most strong and shadow is needed. It is possible to cover the whole street for shadow, but it is also possible to only cover the sidewalk with shadow.
Evaluation: the shutters score the most amount of points for the criterion providing shadow, because the whole street can be covered with shadow. This is also very flexible, it can be used when the sun radiates the strongest but opened again when there is more light wished in the street. Because it can cover the whole street and also the facades of the north side of the street, there will be less heat accumulation. The shutters don't score on cooling the microclimate through evaporation or evapotranspiration. In this design principle there is no vegetation or water involved.



II: moveable shutters		
Provide shadow	50%	10*5=50
Minimise heat accumulation	30%	8*3=24
Cooling by evaporation and evapotranspiration	20%	0
Total score	100%	74

III: Pergola

The pergola is providing the sidewalk at the northern side of the street with shadow and is a nice shaded walkway. The built structure with vertical pillars and horizontal beams support climbing plants. These plants also give coolness by evapotranspiration. The plants chosen for a pergola could be green in winter too, to give extra shelter against wind and precipitation.

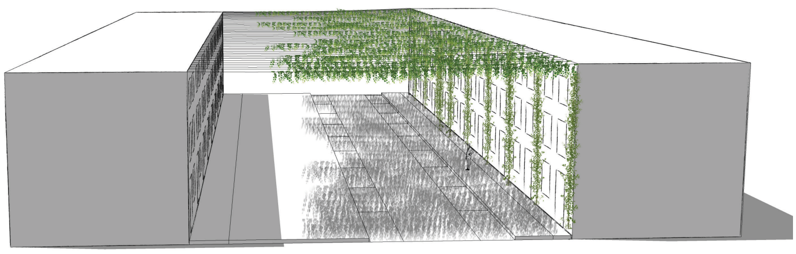
Evaluation: the pergola scores quite good on providing shadow, because you can walk in the shadow during the whole day. It scores also quite good on cooling by evaporation and evapotranspiration, because there is a large amount of plants that give coolness. There is also a fair amount of grass, to give the climbing plants soil to grow in and this contributes to minimising heat accumulation.

III: pergola		
Provide shadow	50%	8*5=40
Minimise heat accumulation	30%	7*3=21
Cooling by evaporation and evapotranspiration	20%	8*2=16
Total score	100%	77

IV: Planted lines

Iron wires are connecting the two sides of the streets and can support climbing plants. These climbing plants will climb up on the north facade. These planted lines will cover the street with shadow. In winter time, the leaves will fall off and provide the street with enough light. Climbing plants like wisteria, passiflora, grape vines or climbing hydrangea are fast growing and will easily climb up.

Evaluation: when the lines are overgrown they will provide a fair amount of shadow in the street. The climbing plants are based in the ground at the northern facade and climb up via this facade. Because this facade is covered with plants the wall will not absorb much heat. The plants will also give coolness through evapotranspiration, but will be less felt on street level.

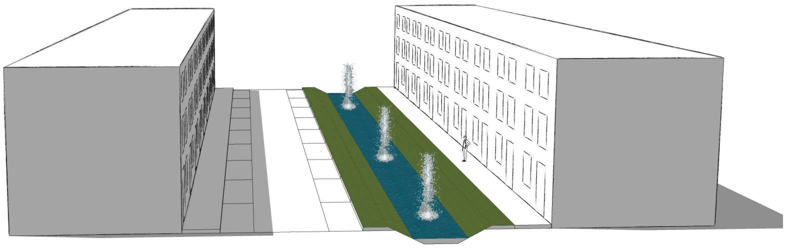


IV: planted lines		
Provide shadow	50%	8*5=40
Minimise heat accumulation	30%	9*3=27
Cooling by evaporation and evapotranspiration	20%	6*2=12
Total score	100%	79

V: Water with fountains

Water is giving coolness through evaporation. Especially moving water, because of the fountains, is giving a lot of coolness because it warms up less by the sun than stagnant water. The spraying water of the fountains also gives the air more humidity. The water plants at the waterfronts also give coolness and will not absorb heat.

Evaluation: the moving and spraying water of the fountains will give a feeling of coolness. Also the water plants can give coolness through evapotranspiration. This design principle is not providing any shadow and therefore scores 0 points on this criterion. The water will not store so much heat, especially because it is moving because of the fountains.

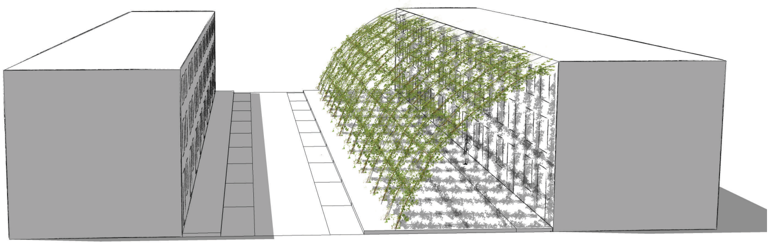


V: water with fountains		
Provide shadow	50%	0
Minimise heat accumulation	30%	6*3=18
Cooling by evaporation and evapotranspiration	20%	10*2=20
Total score	100%	38

VI: Planted tunnels

The construction supports climbing plants to cover the whole tunnel in order to provide the sidewalk with shadow. These climbing plants also give coolness through evapotranspiration. During winter the leaves fall off, so there will be enough light intrusion into the houses. The tunnel gives a nice atmosphere when you walk through it.

Evaluation: the planted tunnel is covering the sidewalk on the north side of the street with shadow. This shadow will be provided by the climbing plants and these will also give coolness through evapotranspiration. The tunnel is covering the northern facade and block the sun, therefore there is not much absorption of the radiation. However, in summer it is permanently blocking out the sun and therefore there is not much light inside the house.

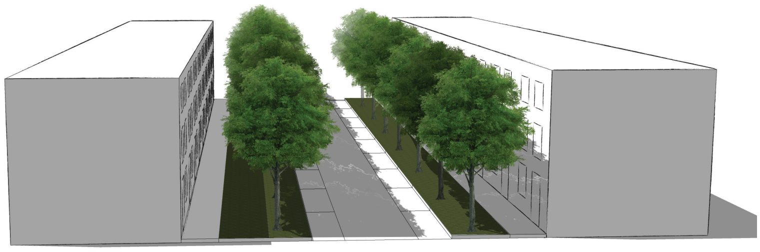


VI: planted tunnel		
Provide shadow	50%	8*5=40
Minimise heat accumulation	30%	8*3=24
Cooling by evaporation and evapotranspiration	20%	10*2=20
Total score	100%	84

VII: Two rows of trees

Two rows of trees at each side of the road give a lot of shade and coolness through evapotranspiration. The trees should be of sufficient height and width to give a big shade. They should be placed a few meters away from each other to cover the street with shadow as much as possible. The trees should be of species that have a high leaf density and do not let too much sunbeams through. They should lose their leaves in winter to let the sun shine through.

Evaluation: the design principle with two rows of trees score very high on all three criteria. Placing trees on both sides of the street is giving a lot of shade on most of the street. Trees also give a lot of coolness through evapotranspiration. Besides that, the trees preferably need soil to grow in instead of pavement. Using grass and less pavement will minimise the heat accumulation.

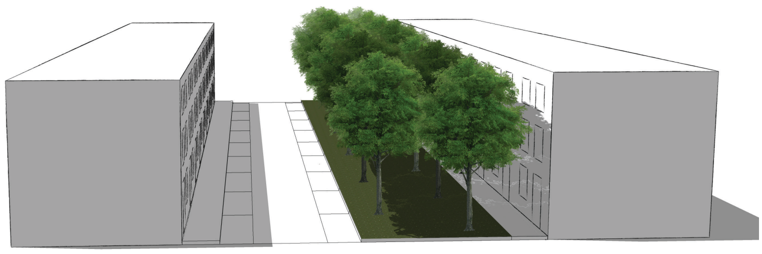


VII: two rows of trees		
Provide shadow	50%	9*5=45
Minimise heat accumulation	30%	9*3=27
Cooling by evaporation and evapotranspiration	20%	9*2=18
Total score	100%	90

VIII: Double row of trees

A double row of trees on the north side of the street is giving a lot of shade and coolness. It is covering the part of the street where there is the most sun. It forms a green buffer in the street. With a diagonal planting lay-out, the trees cover a big area with shade. The trees should be of species that have a high leaf density and do not let too much sunbeams through. They should lose their leaves in winter to let the sun shine through.

Evaluation: a double row of trees on the north side of the street is covering a big part of the street with shadow, but less than the two rows of trees on each side of the street. The south side of the street is still exposed to shortwave radiation. The trees need a big part of the street for growing their roots in the soil. So instead of having pavement, the soil is not accumulating heat so much but instead giving coolness through evaporation. Also the leaves of the trees give coolness through evapotranspiration.



VIII: double row of trees		
Provide shadow	50%	8*5=40
Minimise heat accumulation	30%	8*3=24
Cooling by evaporation and evapotranspiration	20%	9*2=18
Total score	100%	82

IX: Vertical green and row of trees

On the north side of the street, vertical gardens or a structure for climbing plants can be attached. Climbing plants will have to be pruned every year to keep the windows and doors free from plants. Plants on this facade give a nice atmosphere and coolness. Adding a row of trees will give shadow and will contribute to a cool passageway at the northern sidewalk.

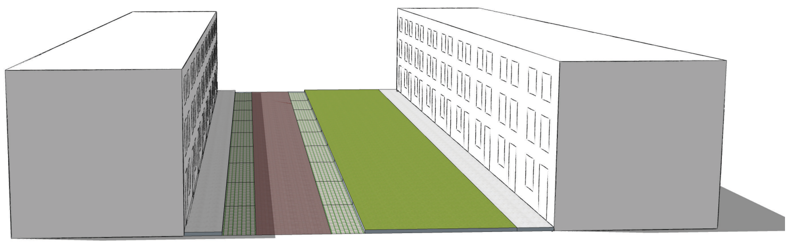
Evaluation: Covering the north facade of the street with a vertical garden or climbing plants is giving a lot of coolness and prevents the wall from absorbing a lot of short-wave radiation. The row of trees is providing the sidewalk with shade and the trees give coolness through evapotranspiration. The southern part of the street where the cars are, is not protected with shade.

IX: Vertical green on facade and one row of trees		
Provide shadow	50%	7*5=35
Minimise heat accumulation	30%	9*3=27
Cooling by evaporation and evapotranspiration	20%	9*2=18
Total score	100%	80

X: Material choice: less pavement, grass tiles, red bricks, light-coloured tiles, grass, vegetation

Less pavement will contribute to less heat accumulation by absorption of short-wave radiation. Using grass or vegetation is giving more coolness and doesn't retain heat as much as pavement does. If pavement must be used, then it is advised to use red bricks, grass tiles or light-coloured tiles. Red bricks reflect shortwave radiation more and grass tiles retain less heat and release heat more easily. Light-coloured tiles are more reflective and therefore absorb less short-wave radiation.

Evaluation: in terms of shadow, the material choice is not contributing at all. However, the material choice does influence the amount of heat accumulation and the cooling very positively. It is also a design principle that could be considered as one that could be used in every situation and in combination with another design principle. Therefore, the low score is not decisive in determining which design principles should be eliminated.



X: material choice		
Provide shadow	50%	0
Minimise heat accumulation	30%	10*3=30
Cooling by evaporation and evapotranspiration	20%	8*2=16
Total score	100%	46

Conclusions

Design principle VII: two rows of trees scores the highest with 90 out of 100 points. Design principle VI: planted tunnel with 84 points and VIII: double row of trees with 82 points score also very high. Interesting to see is that the top three consists of design with trees or another form of vegetation. This proves that making a street more green is the best way to improve thermal comfort in a residential street.

The design principles with the lowest score will be eliminated to design further with. Design principle X: material choice is scoring low, but as already discussed, should still be included. This design principle is of an added value to other design principles and can be applied in different forms. The design principles V: water with fountains, I: moveable shadow screens and II: moveable shutters are scoring very low and are not good enough to take along to the next phase of the research through design process.

		I	II	III	IV	V
Provide shadow	50%	8*5=40	10*5=50	8*5=40	8*5=40	0
Minimise heat accumulation	30%	6*3=18	8*3=24	7*3=21	9*3=27	6*3=18
Cooling by evaporation and evapotranspiration	20%	0	0	8*2=16	6*2=12	10*2=20
Total score	100%	58	74	77	79	38

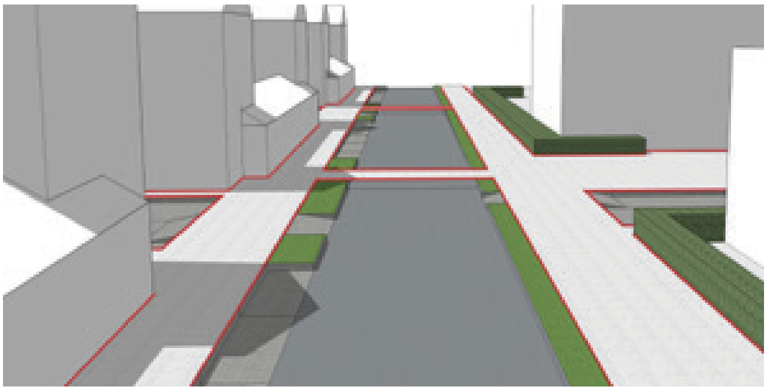
		VI	VII	VIII	IX	X
Provide shadow	50%	8*5=40	9*5=45	8*5=40	7*5=35	0
Minimise heat accumulation	30%	8*3=24	9*3=27	8*3=24	9*3=27	10*3=30
Cooling by evaporation and evapotranspiration	20%	10*2=20	9*2=18	9*2=18	9*2=18	8*2=16
Total score	100%	84	90	82	80	46

4.3 Designing and evaluating principles accessibility

I: Same-level walking

Walking on the same level will make it easier and safer for elderly to walk around the neighbourhood. All crossings should be on the same level as the sidewalks. This prevents elderly from falling over the lowered curbs or getting stuck with their rollators. Also cars will have to slow down at these crossings, because they need to go over a raised crossing. These raised crossings should be placed very frequently.

Evaluation: in terms of safety, connectivity and legibility this design principle scores highest. Because of the absence of lowered curbs and a safe crossing, it scores maximum on safety. The crossings are clear places where to cross and this is easy to understand, therefore it contributes to legibility. If this design principle is applied in the whole neighbourhood, it improves the connectivity.

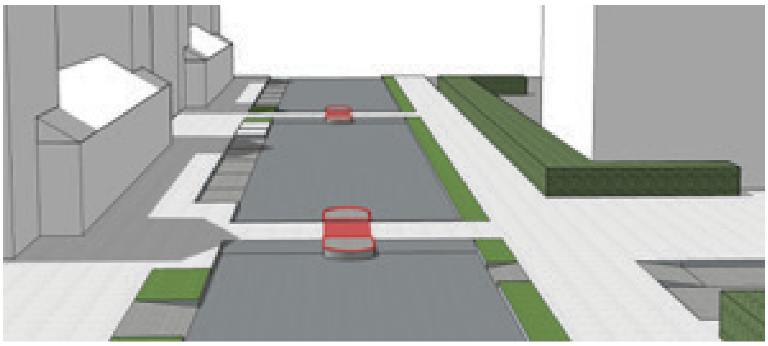


I: same-level walking		
Safety	50%	10*5=50
Connectivity	25%	10*2.5=25
Legibility	25%	10*2.5=25
Total score	100%	100

II: Traffic islands

Traffic islands can shorten the crossing distance by providing a resting place halfway the road. This is especially useful when it is a road with busy traffic. This gives elderly the opportunity to focus on one way traffic at the time and makes it safer and easier to cross the road.

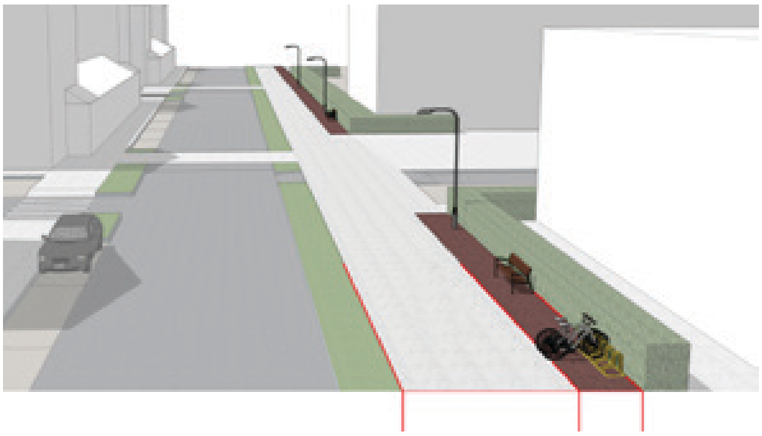
Evaluation: traffic islands score quite high in terms of safety, because the overview on traffic improves. It does not solve the problem of obstacles such as the lowered curbs, although you could think of combining the traffic islands with the design principle of same-level walking to prevent this problem.



II: traffic islands		
Safety	50%	8*5=40
Connectivity	25%	5*2.5=12.5
Legibility	25%	6*2.5=15
Total score	100%	67.5

III: Wide sidewalks of 2 meters and clear of obstacles (separate strip)

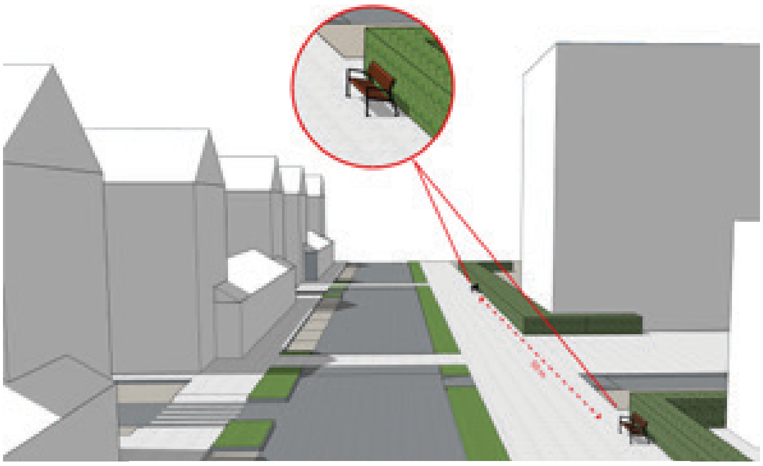
To give people with strollers and wheelchairs enough space at the sidewalk, you need at least 2 meters to pass each other, to make turns and to turn around. This sidewalk should be free from obstacles and these could be bundled together at a separate strip. If there is space needed for parking bicycles or a bench, there should be extra space next to the 2 meters.
Evaluation: a wide enough sidewalk is very important for the accessibility of the neighbourhood because it contributes to safety by reducing the chance of falling over obstacles and manoeuvring between obstacles. It also contributes to the connectivity of the pedestrian network, because when there is a too narrow sidewalk at some point, elderly are forced to find an alternative route.

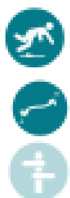


III: wide sidewalk, obstacles seperated		
Safety	50%	9*5=45
Connectivity	25%	9*2.5=22.5
Legibility	25%	8*2.5=20
Total score	100%	87.5

IV: Seating every 50-100 meter

For elderly with some level of mobility impairment or a low capacity to walk a long distance, it is very important to be able to sit down (Thompson, 2013). By placing benches every 50-100 meter, the walking distance for elderly can be extended, because they can take a rest along the way. It could also be a place that leads to social interaction, especially when these benches are situated at a nice place.
Evaluation: placing benches along routes improves the connectivity enormously, because it can extend the reach of destinations of elderly. They also improve the safety, because elderly who get tired tend to fall earlier.





IV: seating every 50-100m		
Safety	50%	7*5=35
Connectivity	25%	10*2.5=25
Legibility	25%	4*2.5=10
Total score	100%	70

V: Clear zoning of the street

By creating a clear zoning in a street, people can understand more easily what the appropriate places are to park their car, where to walk and where to park the bicycle. This will lead to safer situations. By placing green strips between the road and the sidewalk it marks the transition and it contributes to safety, clarity and atmosphere. Making different zones visible vegetation could be used, but also differences in type and colour of materials could be used.

Evaluation: making different zones in a street visible with materials and vegetation contributes to a higher legibility for elderly. It will be more clear and understandable where they can walk and this will give a feeling of safety and this encourages them to go out for a walk.

V: clear zoning of street		
Safety	50%	8*5=40
Connectivity	25%	7*2.5=17.5
Legibility	25%	10*2.5=25
Total score	100%	82.5

VI: Crossings free from view-blocking obstacles

It costs a lot of effort for elderly to see if it is safe to cross the road. Crossings should therefore be free from view-blocking obstacles, such as parked cars, vegetation or bus shelters. Preferably parking places for cars or bus shelters should be situated a few meters away from the crossing. When vegetation is used, it should only contain low perennials, grasses or flower beds to easily look over them. Trees would block the view too much and should therefore also be situated a few meters away from the crossing.

Evaluation: a clear crossing improves the safety and prevents accidents. It is also important for elderly to have this clear view to be able to orientate and find their way easily.

VI: crossings free from view-blocking obstacles		
Safety	50%	8*5=40
Connectivity	25%	7*2.5=17.5
Legibility	25%	8*2.5=20
Total score	100%	77.5

VII: Free sight: low perennials and high trees

When using vegetation in a street, it is advisable to use either low perennials, grasses and flower beds or high trees so that the view on eye-height keeps free. It can also be a combination of low vegetation and high trees. This will contribute to a safer feeling for elderly because research shows that older people feel unsafe when they have to walk past high and dense shrubs. They can also more easily keep the overview of the street.

Evaluation: a free sight contributes to safety in two ways, as described above. The free view on the street also is helpful for elderly to orientate and understand where they have to cross the street.

VII: free sight		
Safety	50%	8*5=40
Connectivity	25%	7*2.5=17.5
Legibility	25%	8*2.5=20
Total score	100%	77.5

VIII: Landmarks

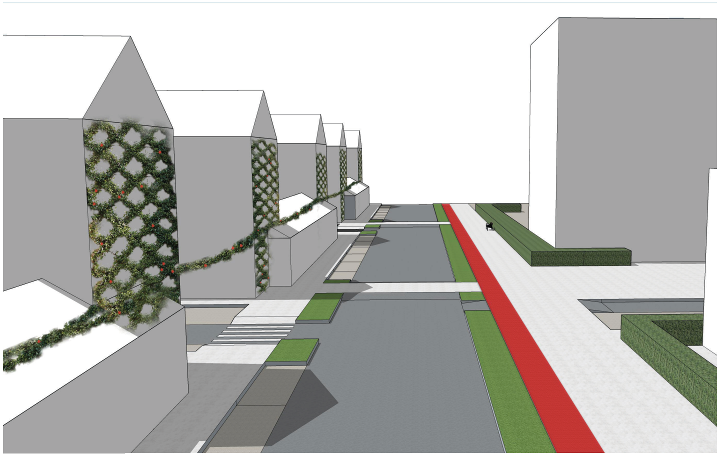
Landmarks can be placed on remarkable places or crossings to improve the sense of orientation. The landmark can be recognised from a bigger distance. This can be a big tree, a statue or something else that stands out.

Evaluation: a landmark is a good way to give people a sense of orientation and recognise where they need to go. It does not help to create a more safe surrounding for elderly, but they could be used to mark a specific route which contributes to a well-connected network.

VIII: landmarks		
Safety	50%	0
Connectivity	25%	8*2.5=20
Legibility	25%	9*2.5=22.5
Total score	100%	42.5

IX: Recognisable colours or plants to mark main routes

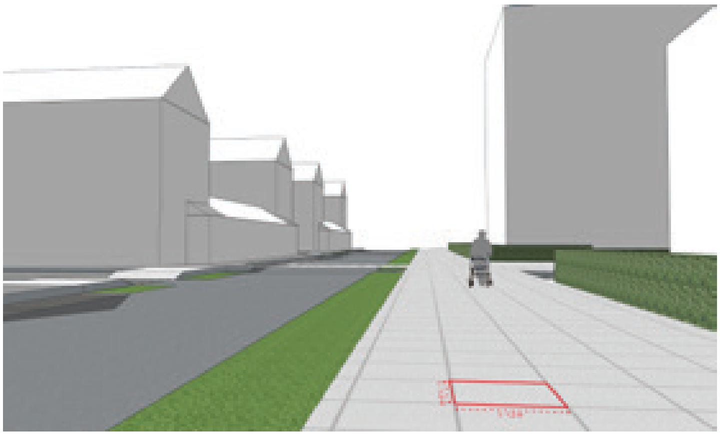
With colours or plants, a main route can be marked to improve the sense of orientation. Colours could be used in the pavement, in the facade of buildings or on street furniture to mark a route. When using plants as recognisable marking, it should be very clear that it is the same species, it is placed at a special place or it is hanging at the facades. This marking could be done for instance at routes that lead to shops, public transport stops or important axes through a neighbourhood. They can also mark the sidewalks where walking for elderly is the best, such as where there is the most space, benches along the way or the shaded side of the street.
Evaluation: markings are very helpful in contributing to a better connected and understandable pedestrian network. However, it is important not to use too much markings within a neighbourhood because then it could become confusing and routes are not distinguished anymore.



IX: recognisable colours or plants along routes		
Safety	50%	0
Connectivity	25%	10*2.5=25
Legibility	25%	10*2.5=25
Total score	100%	50

X: Big tiles, less seams

A smooth pavement is very important for elderly, so that the risk of falling over is minimised. Using certain materials can improve this. Using small bricks or tiles is not recommended, because then there are a lot of seams. Using asphalt is also not recommended, because it is very vulnerable for cracks because of growing tree roots. Big tiles are the best option, because they have less seams and are heavy and therefore stay in place.
Evaluation: choosing a certain type of pavement is important in helping to recognise which parts of the street is meant as pedestrian walkway. It is also essential for safety that the pavement is smooth and has no tiles that are missing or are slanted. Big tiles are more stable and have less seams.

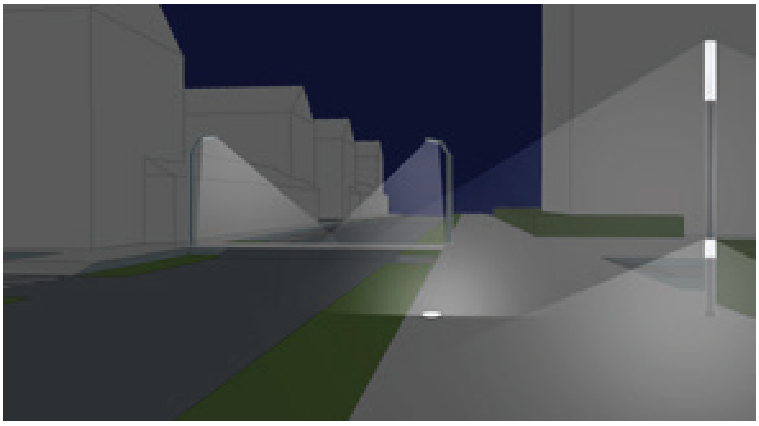


X: material choice, big tiles		
Safety	50%	10*5=50
Connectivity	25%	4*2.5=10
Legibility	25%	6*2.5=15
Total score	100%	75

XI: Lighting at crossings and different heights

Some elderly have trouble to have a good view at night and lighting is very important to overcome these problems. Good lighting along the walking route also gives a sense of safety. Good lighting at crossings is important to give car drivers good sight when people want to cross when it is dark. It can also highlight where you can find a safe crossing. Lighting at different heights is important for elderly because they often have limited visibility at night. With high lighting it lights the whole street and with low lighting it is making the pavement more visible, so that elderly can notice irregularities.

Evaluation: lighting is very important for giving elderly a sense of safety and providing good sight at night. This prevents them from falling over irregularities. It is also an important aspect that contributes in wayfinding.



XI: lighting		
Safety	50%	8*5=40
Connectivity	25%	7*2.5=17.5
Legibility	25%	8*2.5=20
Total score	100%	77.5

Conclusions

The design principle I: same-level walking is scoring the best: 100 out of 100 points. It is scoring maximal on all criteria. Second best with 87.5 points, is III: wide sidewalk with obstacle strip and third with 82.5 point is V: zoning. It is interesting to see that these design principles are all longitudinal and might be applicable through a whole neighbourhood.

The three design principles that score lowest will be eliminated. These are VIII: landmarks with 42.5 points, IX: recognisable colours or plants with 50 points and II: traffic islands with 67.5 points.

		I	II	III	IV	V	VI
Safety	50%	10*5=50	8*5=40	9*5=45	7*5=35	8*5=40	8*5=40
Connectivity	25%	10*2.5=25	5*2.5=12.5	9*2.5=22.5	10*2.5=25	7*2.5=17.5	7*2.5=17.5
Legibility	25%	10*2.5=25	6*2.5=15	8*2.5=20	4*2.5=10	10*2.5=25	8*2.5=20
Total score	100%	100	67.5	87.5	70	82.5	77.5

		VII	VIII	IX	X	XI
Safety	50%	8*5=40	0	0	10*5=50	8*5=40
Connectivity	25%	7*2.5=17.5	8*2.5=20	10*2.5=25	4*2.5=10	7*2.5=17.5
Legibility	25%	8*2.5=20	9*2.5=22.5	10*2.5=25	6*2.5=15	8*2.5=20
Total score	100%	77.5	42.5	50	75	77.5

chapter 5 | integrated design principles

5.1 Introduction

In the previous chapter a total of 21 design principles were developed in order to answer the two sub research questions. These design principles were evaluated and this resulted in the elimination of three design principles for accessibility and three for thermal comfort. The 15 design principles that were left will be used to form integrated design principles in the coming chapter and therewith answer the main research question: ***What design principles can be developed to improve thermal comfort and accessibility for elderly in residential streets?***

The used design principles are:

Accessibility
- Same-level walking and crossing
- Seating every 50-100 meter
- Wide sidewalk of at least 2 meter without obstacles.
- Obstacles in a separated strip.
- Clear zoning of the street
- Crossings free from view-blocking obstacles
- Free sight: low perennials and high trees
- Big tiles, with less seams
- Lighting at crossings and different heights

Thermal comfort
- Pergola with climbing plants
- Planted lines across the street
- Planted tunnel at the north side of the street
- Vertical green on the north facade and a row of trees
- Double row of trees
- Two rows of trees
- Using grass tiles for parking spaces, red bricks for the road, as much grass and vegetation as possible (less pavement), light-coloured tiles for the sidewalk

The integrated design principles consist of at least one design principle from thermal comfort and one design principle of accessibility, but might even have more of them combined. I combined these design principles in many sketches and try to figure out what is the best way to combine them, this was an iterative process of designing and testing. This resulted in seven designs, which I will describe and explain in this chapter. The integrated design principles will be showed in the newly constructed test bed (see chapter 3.4.4) and will be accompanied by small sketches of the separate design principles that are used. These small sketches give insight in which design principles from thermal comfort and which from accessibility are used.

These seven integrated design principle were evaluated according to the six criteria from the previous phase and four new criteria. In chapter 3.4.6 was explained how this evaluation was conducted and how the criteria were weighed. The used criteria are:

- Provide shadow
- Minimise heat accumulation
- Cooling by evaporation and evapotranspiration
- Safety
- Connectivity
- Legibility

- Construction costs. If the design principle scores very low on this criterion, it costs a lot of money to construct this design. If it scores high, then it is more appealing because the costs are lower.
- Maintenance. This says something about if this solution needs very regular maintenance or not, and thus costs a lot of money after the construction. If the design principle scores high on this criterion, then it means that there is only a small amount of maintenance needed. If it scores low, then the solution is expensive and labour-intensive.
- Feasibility. This says something about how realistic the solution is. A high score means an achievable solution.
- Seasonality. A design must function well in every season, not only in summer. If the design principle scores high on this criterion, then this solution is suitable for every season.

5.2 Designing and evaluating the integrated design principles

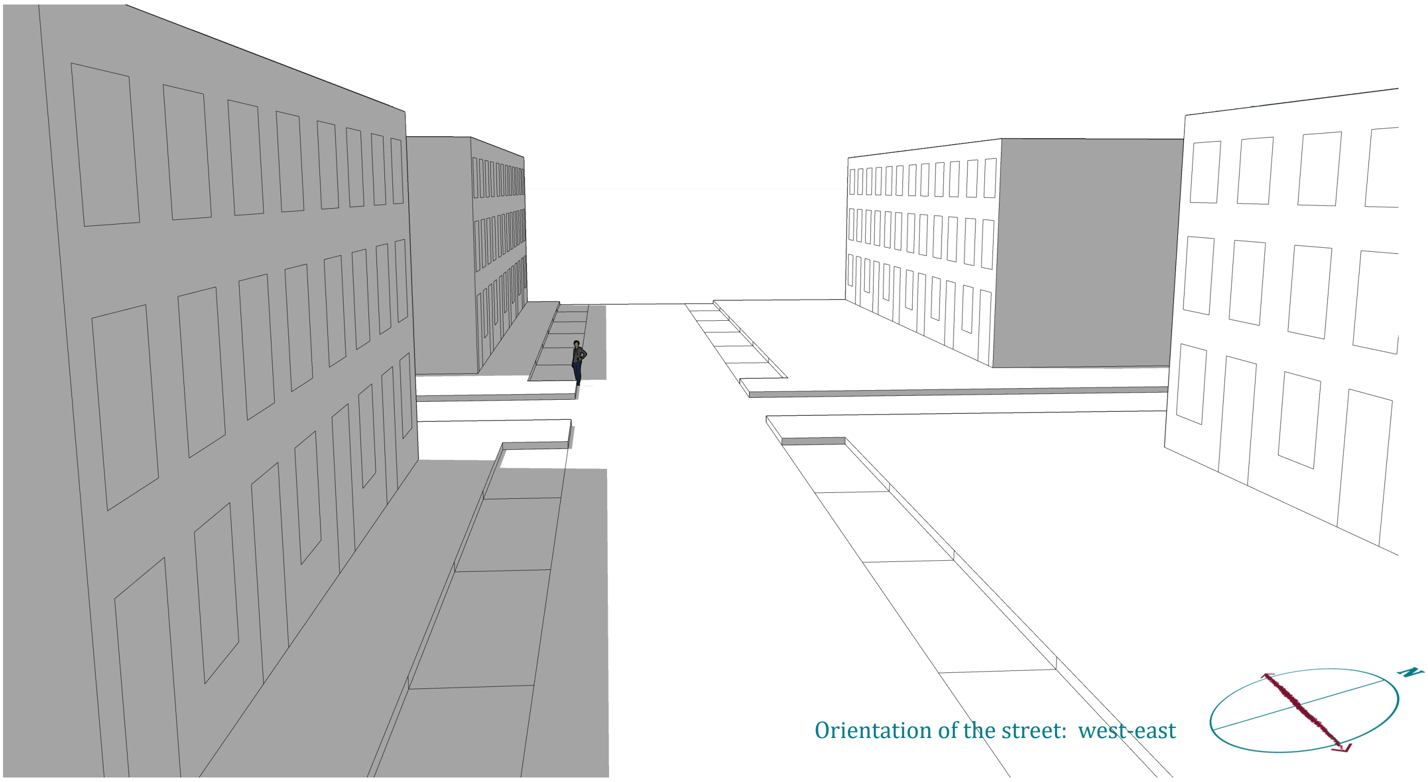
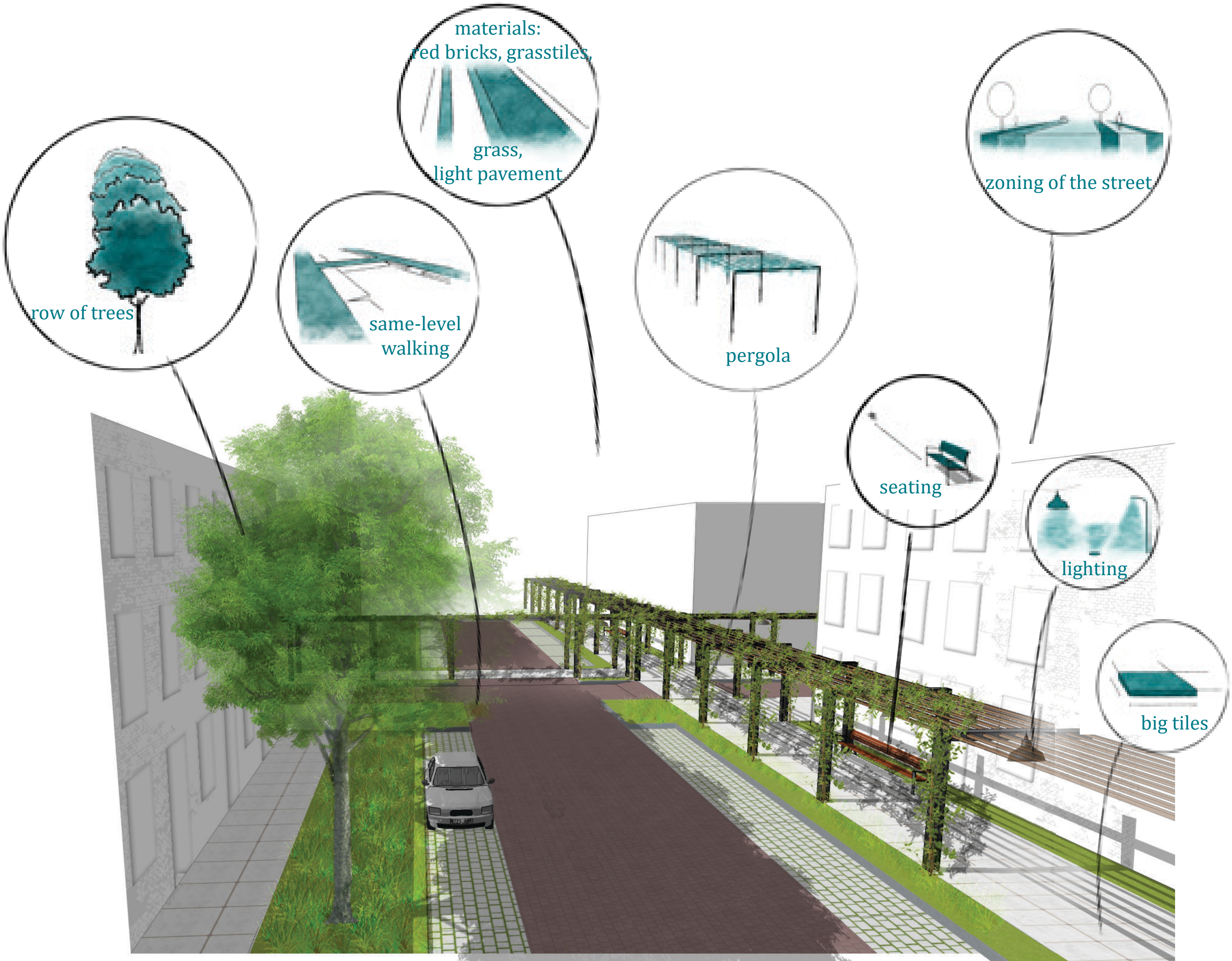


Figure 36. The test bed that will be used to develop integrated design principles.



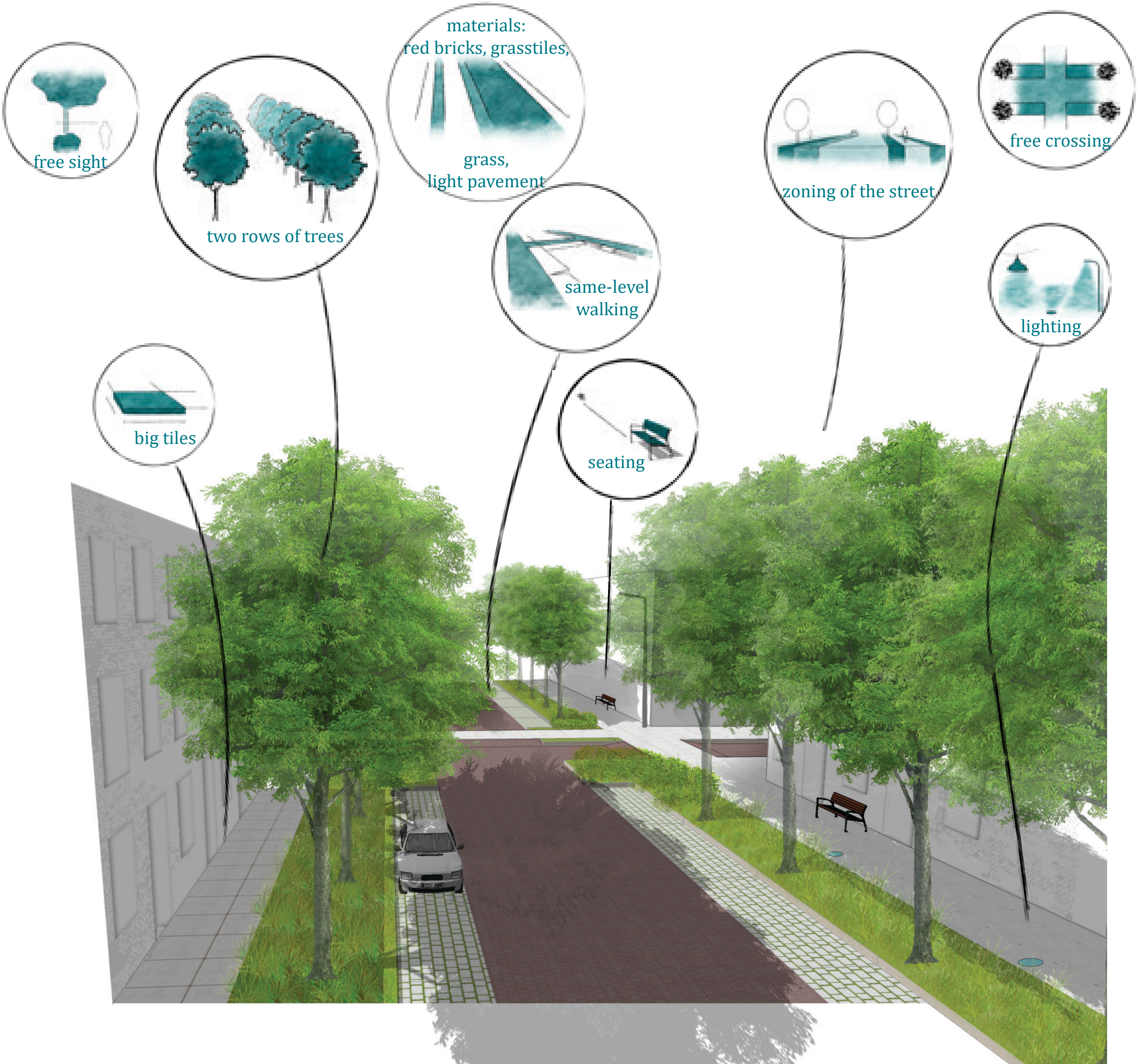
I | The pergola provides a shaded walkway and protects elderly from the sun. The climbing plants also give coolness. The used plants can be a mixture of wisteria, grape vine, passiflora and/or climbing hydrangea. The walkway is very wide and gives enough space to pass each other: 3.5 meter. The pergola is also well lit so it makes it more safe at night. Under the pergola, benches are situated to provide places to rest. Elderly can even cross the street at the same level under the pergola.

Thermal comfort: the row of trees and the pergola together provide a lot of shade and cover a big part of the street. It scores a bit lower on minimising heat accumulation because the interventions do not cover the northern facade of the street, which will warm up very easily. It scores quite well on cooling because this design makes use of a fair amount of vegetation and trees.

Accessibility: this design gets a maximum score on connectivity, because the pergola and continuous sidewalk at the same level contributes to a well-connected network. However, because of this connected pergola, the safety is compromised because it blocks the view at crossings from the pedestrians, as well as from the car driver or cyclist. Especially the pergola is contributing to a legible pedestrian network, because it makes very clear where the elderly can safely walk and it gives a very clear zoning to the street.

General design aspects: this design scores high on seasonality, because the leaves of the trees and pergola will drop in winter and this will make sure that the houses will have enough light intrusion. The pergola is a big intervention that costs a lot of money to construct and to maintain. Also the feasibility scores low, because in this form it is not very realistic that the pergola will also cross the street, because it will block larger carriers. It needs adjustments to be able to carry out this design.

			I
Provide shadow	40%	20%	8*2= 16
Minimise heat accumulation		12%	6*1.2= 7.2
Cooling by evaporation and evapotranspiration		8%	7*0.8= 5.6
Safety	40%	20%	5*2= 10
Connectivity		10%	10*1= 10
Legibility		10%	8*1= 8
Construction costs	20%	5%	4*0.5= 2
Maintenance		5%	5*0.5= 2.5
Feasibility		5%	4*0.5= 2
Seasonality		5%	10*0.5= 5
Total score	100%	100%	68.3



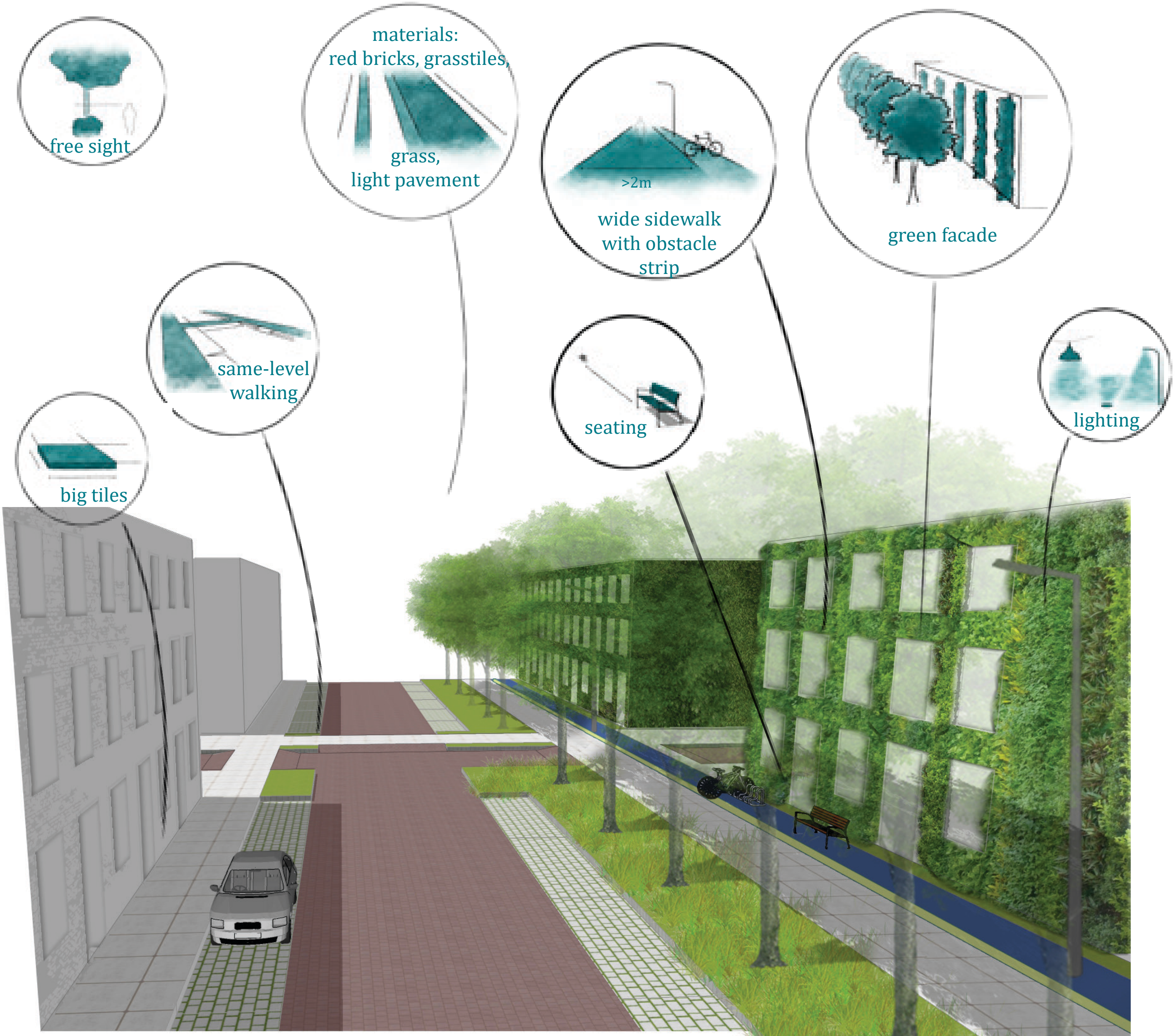
II | This design consists of two rows of trees which are covering big parts of the street and give a lot of shade and coolness. By keeping the vegetation under the trees low and the space around the crossing free from trees, there is a good overview. The two green strips with trees on each side of the road is separating the pedestrians from the other traffic.

Thermal comfort: the two rows of trees provide a lot of shade in the street and also give a lot of coolness by evapotranspiration. The green strips with trees are also minimising heat accumulation, because it reduces the amount of pavement in the street.

Accessibility: this design contributes to a safe street because of the clear overview and the raised crossings. The two rows of trees separate the street from the sidewalks, which indicates very clearly where to walk. Therefore the score on legibility is good.

General design aspects: this design is very realistic to actually carry out, because it scores very well on feasibility and seasonality. Placing trees in a street and constructing raised crossings are not unfamiliar in the Netherlands.

			II
Provide shadow	40%	20%	8*2= 16
Minimise heat accumulation		12%	8*1.2= 9.6
Cooling by evaporation and evapotranspiration		8%	9*0.8= 7.2
Safety	40%	20%	7*2= 14
Connectivity		10%	6*1= 6
Legibility		10%	7*1= 7
Construction costs	20%	5%	8*0.5= 4
Maintenance		5%	7*0.5= 3.5
Feasibility		5%	10*0.5= 5
Seasonality		5%	10*0.5= 5
Total score	100%	100%	77.3



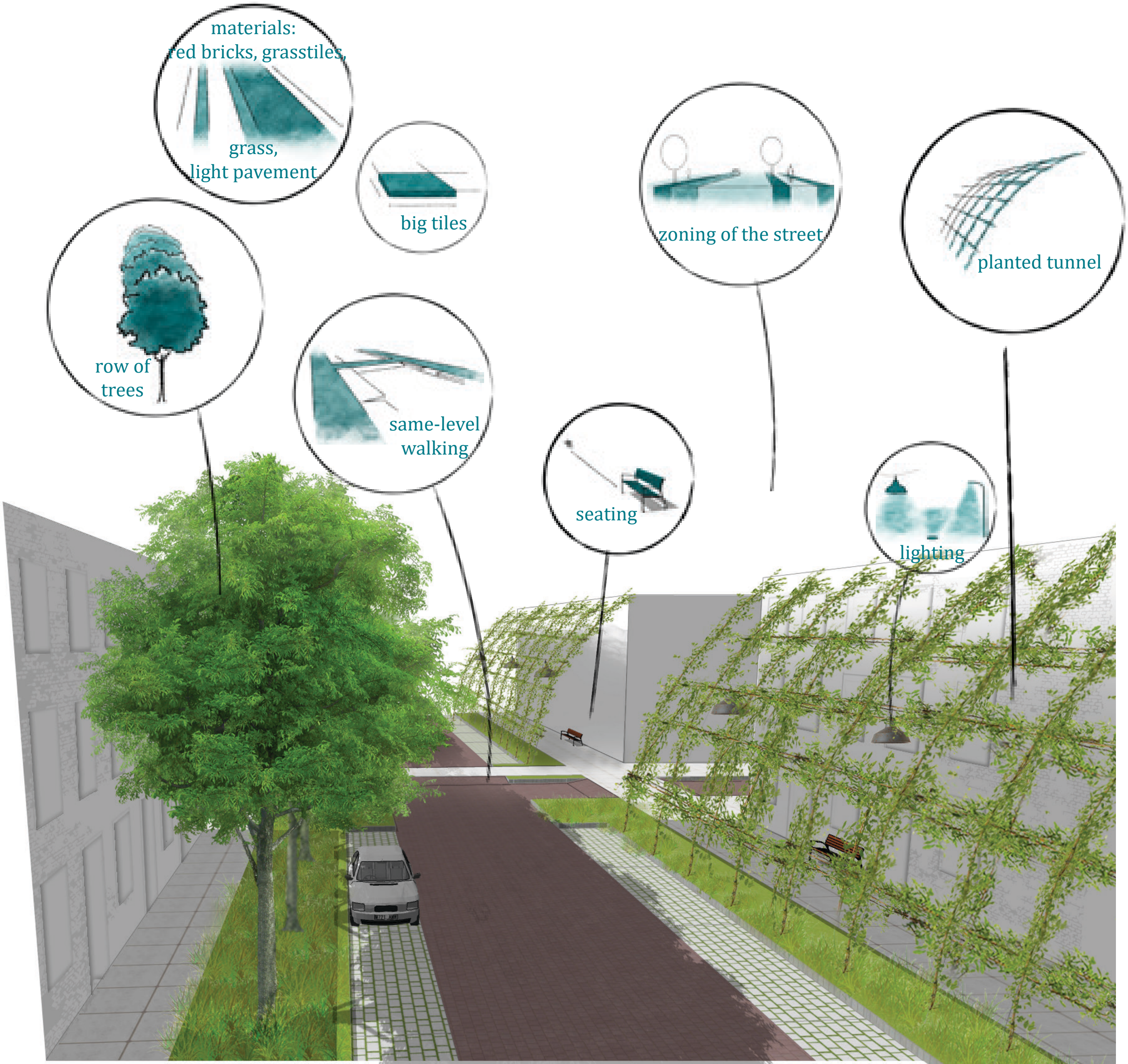
III | The interventions in this design are focused on the north side of the street, to make a very thermally comfortable and accessible walkway. It makes sure that elderly have all the space they need to walk there easily. It has a wide sidewalk and a separated strip for obstacles such as benches, lighting and parked bikes. The vertical garden on the north facade provides extra coolness and also prevents the brick wall from warming up.

Thermal comfort: although this design is providing a thermally comfortable north side of the street, it is not scoring very well overall. This is because there is not much shadow in the rest of the street and there is relatively a large amount of pavement. The design does score very well on cooling by evaporation and evapotranspiration, because the row of trees and the vertical garden give a lot of coolness.

Accessibility: the three scores for accessibility are maximum, because there is a lot of space for elderly on the sidewalk. It is very safe, because they are not obstructed by loose obstacles. The obstacle strip gives enough space to benches and bike parking spots, and has a light strip, which contribute to safety and connectivity. The colour contribute to a clear, understandable walkway through the whole neighbourhood.

General design aspects: the vertical garden is asking regular maintenance to keep the plants away from the windows and doors. It depends on the type of construction of the vertical garden how high the costs will be. The construction costs will also rise because of the extra type of material and light strip in the separate obstacle strip.

			III
Provide shadow	40%	20%	3*2= 6
Minimise heat accumulation		12%	4*1.2= 4.8
Cooling by evaporation and evapotranspiration		8%	8*0.8= 6.4
Safety	40%	20%	10*2= 20
Connectivity		10%	10*1= 10
Legibility		10%	10*1= 10
Construction costs	20%	5%	3*0.5= 1.5
Maintenance		5%	6*0.5= 3
Feasibility		5%	8*0.5= 4
Seasonality		5%	8*0.5= 4
Total score	100%	100%	69.7



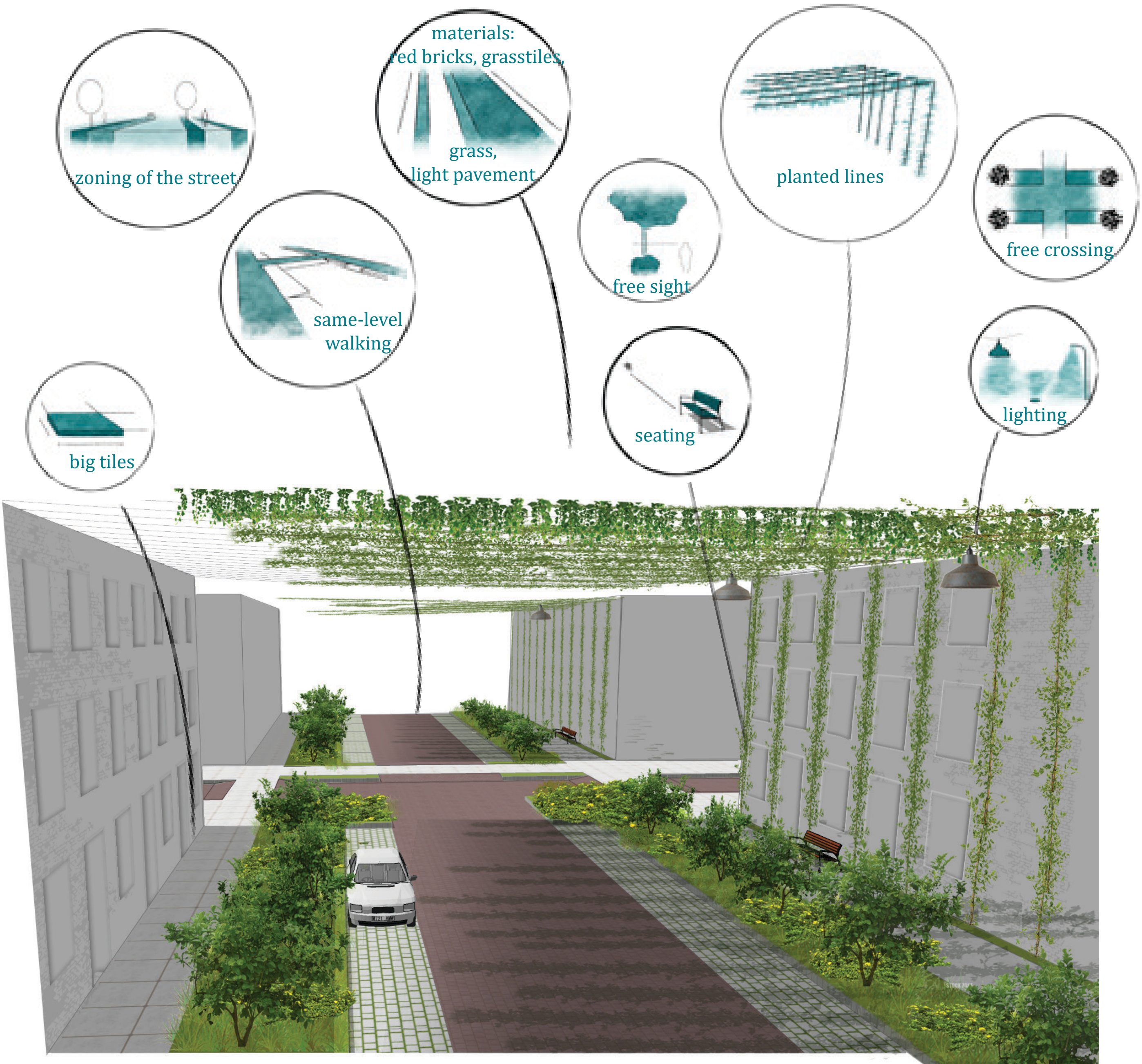
IV | This design has a row of trees and a planted tunnel to provide shade, but also have a cooling effect. A mixture of fast growing climbing plants can be used, so there is a fast result. The planted tunnel is providing a nice walkway for elderly, where they can walk and sit on benches safe and separated from other traffic. The tunnel is well lit and very efficient in used space. The tunnel is very recognisable and therefore understandable as walkway.

Thermal comfort: this design is providing a lot of shadow because of the row of trees and the planted tunnel. The tunnel is a very thermally comfortable walkway with shadow and cooling of the plants. Since the tunnel is attached to the facade, the brick wall is not accumulating very much heat.

Accessibility: in terms of safety, the design is scoring quite well. The raised crossings provide safe circumstances to cross the road and within the tunnel, elderly walk and sit protected from the traffic. There is also enough space for a wide sidewalk and benches. However, the view could be blocked by the climbing plants so elderly could feel a bit unsafe. The tunnel contributes to the connectivity of the pedestrian network and legibility of where to walk.

General design aspects: in particular the planted tunnel will cost quite some money to construct and to maintain. The climbing plants can grow rapidly, but need maintenance regularly to not overgrow everything. The plants should also be cut off when they grow to high, so that there will be still light intrusion in the houses. It also scores good on seasonality, because during winter the climbing plants and trees will drop their leaves, so there will be enough light intrusion.

			IV
Provide shadow	40%	20%	10*2= 20
Minimise heat accumulation		12%	8*1.2= 9.6
Cooling by evaporation and evapotranspiration		8%	10*0.8= 8
Safety	40%	20%	8*2= 16
Connectivity		10%	9*1= 9
Legibility		10%	9*1= 9
Construction costs	20%	5%	4*0.5= 2
Maintenance		5%	4*0.5= 2
Feasibility		5%	8*0.5= 4
Seasonality		5%	8*0.5= 4
Total score	100%	100%	83.6



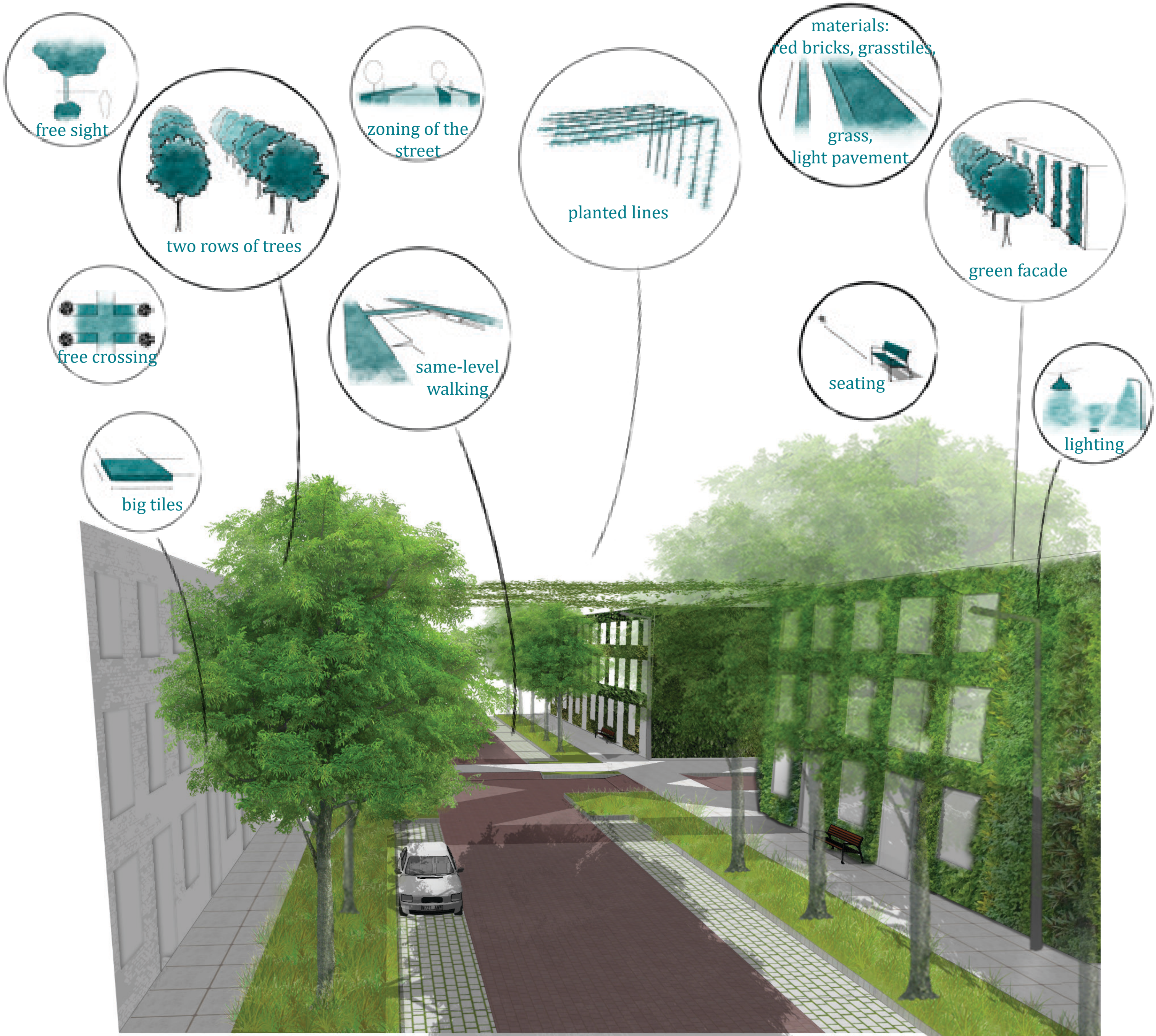
V | This design is the only one without making use of trees. The thermal comfort comes from planted lines above the street and on the northern facade, and from the shrubs and grasses at street level. This use of vegetation gives a totally different look in the street, with more clear overviews and no risks of tree roots wrecking the tiles.

Thermal comfort: in this design there are no trees, so shadow and cooling must come from other elements. The planted lines will provide shadow, but it depends on the density of the plants. The plants cover the northern facade very well, so there will be less heat accumulation. The shrubs and grasses will give less coolness through evapotranspiration than trees would do.

Accessibility: the design is very clear and there are no view-blocking elements, although the shrubs needed to be maintained very well to not grow too big. Therefore it scores high on safety. The lines can be used to hang up lighting, so no lampposts are needed. Sitting on a bench gives a good view on the street and on nice vegetation.

General design aspects: the shrubs and climbing plants ask for regular maintenance and also the falling leaves need to be removed. However, this design is very realistic and fits very well in this street profile. During winter, the leaves from the climbing plants fall down, so there will be enough light intrusion.

			V
Provide shadow	40%	20%	6*2= 12
Minimise heat accumulation		12%	10*1.2= 12
Cooling by evaporation and evapotranspiration		8%	5*0.8= 4
Safety	40%	20%	8*2= 16
Connectivity		10%	6*1= 6
Legibility		10%	6*1= 6
Construction costs	20%	5%	6*0.5= 3
Maintenance		5%	6*0.5= 3
Feasibility		5%	9*0.5= 4.5
Seasonality		5%	7*0.5= 3.5
Total score	100%	100%	70



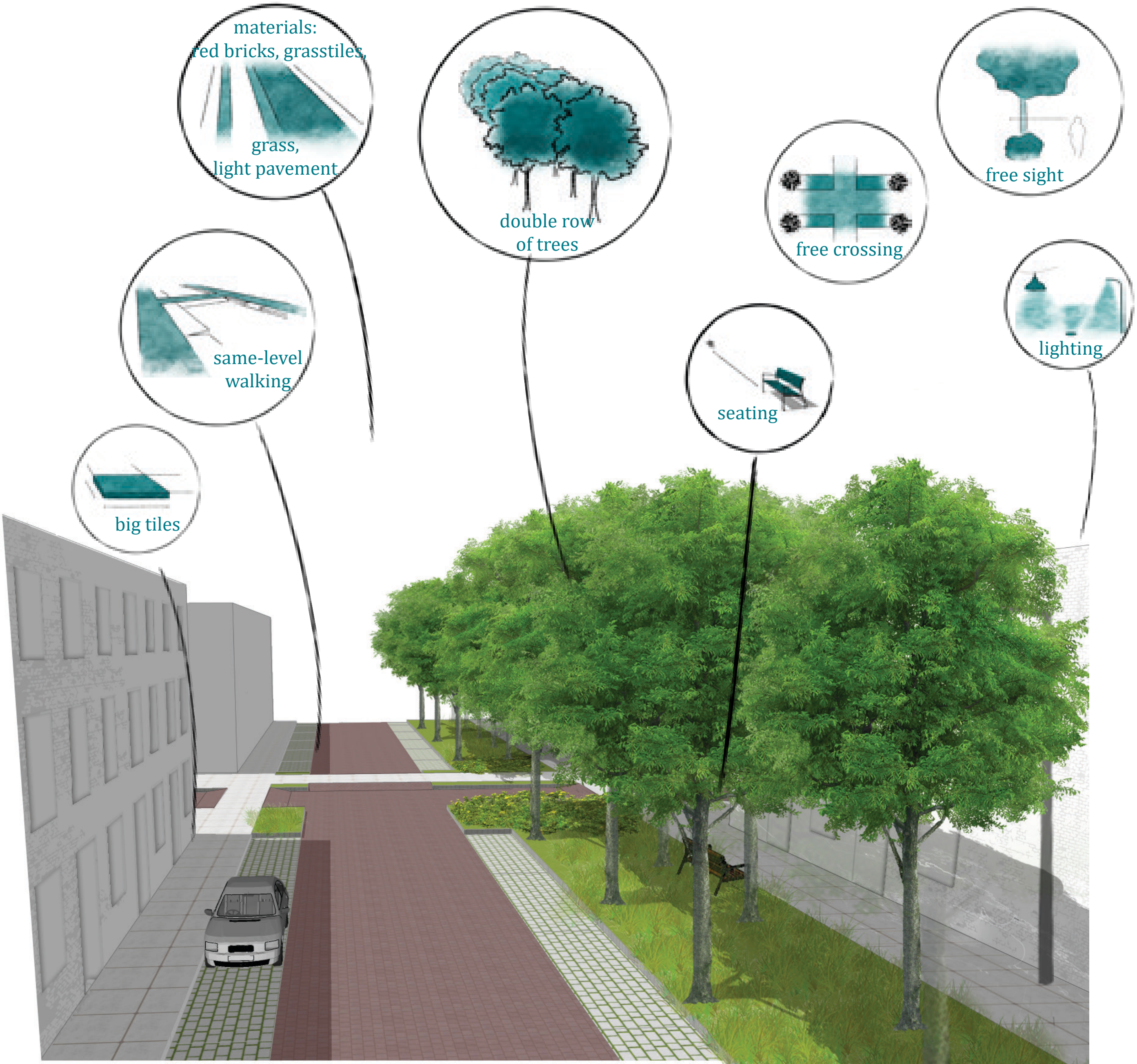
VI | This design is a green oasis, with its rows of trees, vertical garden on the northern façade and planted lines. It creates a very pleasant, thermally comfortable public space. It has nice places for seating. The design makes sure that the crossing is free from trees and therefore gives a good overview. The planted lines across the crossing provide extra shadow and make a crossing recognisable.

Thermal comfort: the score for thermal comfort is maximum. There are two rows of trees that provide a lot of shadow and coolness. The vertical garden on the northern façade is cooling the environment and prevents the wall from accumulating heat. Also the planted lines provide the crossings with shadow.

Accessibility: the planted lines contribute to a sense of orientation and therefore legibility score very good. The crossings are kept free from view-blocking elements and the crossing can be crossed on the same level as the sidewalk, so safety is scoring very well. The planted lines and vertical garden can also contribute to the marking of a certain route, which contributes to connectivity.

General design aspects: the maintenance of this design is very labour-intensive, because there are a lot of green elements that needs to be maintained. Also the amount of green contributes to high construction costs. Therefore, the design is not very feasible.

			VI
Provide shadow	40%	20%	10*2= 20
Minimise heat accumulation		12%	10*1.2= 12
Cooling by evaporation and evapotranspiration		8%	10*0.8= 8
Safety	40%	20%	8*2= 16
Connectivity		10%	8*1= 8
Legibility		10%	8*1= 8
Construction costs	20%	5%	4*0.5= 2
Maintenance		5%	3*0.5= 1.5
Feasibility		5%	6*0.5= 3
Seasonality		5%	8*0.5= 4
Total score	100%	100%	82.5



VII | The double row of trees is creating a big green buffer between the street and the sidewalk. There will always be shadow on the sidewalk on the middle of the day so this gives a very thermally comfortable environment to walk for elderly. Benches can be placed under the trees for a nice seating atmosphere.

Thermal comfort: the double row of trees give a lot of coolness. It provides a lot of shadow to the northern side of the street, but unfortunately not to the rest of the street. The rest of the street is all paved and there a lot of heat accumulates.

Accessibility: there is enough room for a wide enough sidewalk and benches can be placed under the trees. Besides that, the crossing is kept free from trees, so that is why the score for safety is quite good. The rows of trees can accentuate the walking route, therefore connectivity scores quite well. The absence of other vegetation under the trees and the free crossings contribute to a good overview and thus to legibility.

General design aspects: this design has rather simple interventions that do not have to cost a lot of money. Maintaining the trees and its fallen off leaves needs to be done once or twice a year, but that is not a big problem. Also technically, this design is very realistic and scores well on feasibility.

			VII
Provide shadow	40%	20%	4*2= 8
Minimise heat accumulation		12%	6*1.2= 7.2
Cooling by evaporation and evapotranspiration		8%	9*0.8= 7.2
Safety	40%	20%	6*2= 12
Connectivity		10%	6*1= 6
Legibility		10%	6*1= 6
Construction costs	20%	5%	8*0.5= 4
Maintenance		5%	8*0.5= 4
Feasibility		5%	10*0.5= 5
Seasonality		5%	10*0.5= 5
Total score	100%	100%	64.4

5.3 Final results

Design IV comes out as the best option to make residential streets more thermally comfortable and accessible for elderly. The second and third best solutions, design VI and II, follow very closely with also high scores. Design IV is a good solution because it combines a lot of greenery with enough space and accessibility for elderly. The planted tunnel gives a lot of thermal comfort by providing a lot of shade and coolness. Because the tunnel covers the north façade of the street, the heat accumulation is also minimised. The green tunnel is a green oasis with a very pleasant atmosphere. Also during other seasons, people are protected from wind and precipitation. In winter the leaves will fall off, so there will be enough light intrusion for the houses. Besides that, the climbing plants can be maintained well and they could be pruned before they grow entirely to the top of the houses. This design also scores very high on the criteria for accessibility. The tunnel is attractive to walk through and recognisable as a nice walkway. Elderly are protected from cars and it is not possible to park the cars partly on the sidewalk. There is also enough space for a bench and other obstacles. Lighting can be hanged in the tunnel framework.

Design VI is scoring very well on improving thermal comfort of the street. Many possible green solutions are being used. However, this costs a lot of construction costs and maintenance, so the question arises if this is a feasible solution and if a municipality is willing to construct this.
Design II is a design that is partly already seen a lot, with a row of trees on each side of the street. However, this design also gives enough space for elderly on the sidewalk.

As can be seen, all integrated design principles consist of a certain material use. This turned out to be the best working materials. In terms of accessibility, the choice of tiles on the sidewalk were big tiles of at least 1 by 1 meter, but they can be bigger. This is to have less seams and less risk of crooked tiles where elderly can fall over. The tiles should have a light colour, to reflect incoming shortwave radiation and not absorb a lot of heat. The parking places are made of grass tiles, to prevent heat accumulation as much as possible. Also the amount of pavement is reduced as much as possible and replaced by grass or other vegetation. The street is not made of asphalt, but of red brick stones because of the higher albedo.

			I	II	III	IV	V	VI	VII
Provide shadow	40%	20%	8*2= 16	8*2= 16	3*2= 6	10*2= 20	6*2= 12	10*2= 20	4*2= 8
Minimise heat accumulation		12%	6*1.2= 7.2	8*1.2= 9.6	4*1.2= 4.8	8*1.2= 9.6	10*1.2= 12	10*1.2= 12	6*1.2= 7.2
Cooling by evaporation and evapotranspiration		8%	7*0.8= 5.6	9*0.8= 7.2	8*0.8= 6.4	10*0.8= 8	5*0.8= 4	10*0.8= 8	9*0.8= 7.2
Safety	40%	20%	5*2= 10	7*2= 14	10*2= 20	8*2= 16	8*2= 16	8*2= 16	6*2= 12
Connectivity		10%	10*1= 10	6*1= 6	10*1= 10	9*1= 9	6*1= 6	8*1= 8	6*1= 6
Legibility		10%	8*1= 8	7*1= 7	10*1= 10	9*1= 9	6*1= 6	8*1= 8	6*1= 6
Construction costs	20%	5%	4*0.5= 2	8*0.5= 4	3*0.5= 1.5	4*0.5= 2	6*0.5= 3	4*0.5= 2	8*0.5= 4
Maintenance		5%	5*0.5= 2.5	7*0.5= 3.5	6*0.5= 3	4*0.5= 2	6*0.5= 3	3*0.5= 1.5	8*0.5= 4
Feasibility		5%	4*0.5= 2	10*0.5= 5	8*0.5= 4	8*0.5= 4	9*0.5= 4.5	6*0.5= 3	10*0.5= 5
Seasonality		5%	10*0.5= 5	10*0.5= 5	8*0.5= 4	8*0.5= 4	7*0.5= 3.5	8*0.5= 4	10*0.5= 5
Total score	100%	100%	68.3	77.3	69.7	83.6	70	82.5	64.4

Figure 37. Integrated design principle IV, scored as the best result.

As can be seen in the overview with scores, design III ends at the fifth place. It does not score very well in terms of thermal comfort, because a big part of the street is still exposed to the sun and a big amount of the street is paved. However, this design still scores quite high, because of the maximum score it gets for the three criteria to improve the accessibility. The design interventions used to improve the accessibility are very different from the other designs and therefore I still want to show them in this visual. This also shows the differences in design when decisions are being made to give either (in this case) accessibility or thermal comfort more priority.

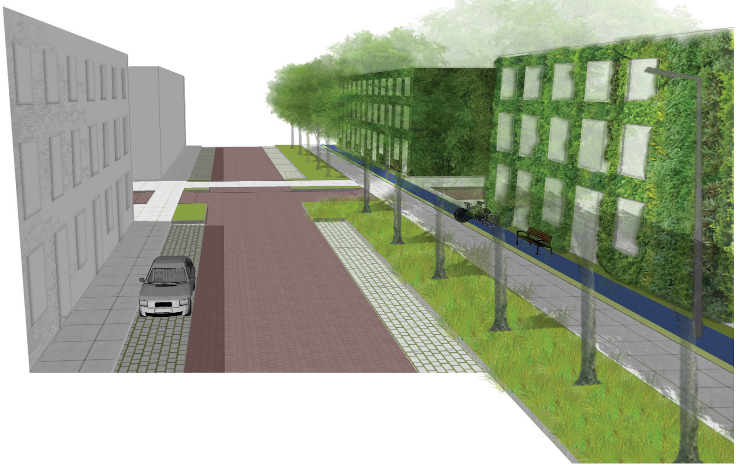


Figure 38. Integrated design principle III, scored as fifth, gives a total different lay-out and atmosphere.

chapter 6 | conclusions and discussion

6.1 Conclusions

The number of elderly in the Netherlands is growing rapidly and this asks for a shift towards a more ageing-proof society. To make a neighbourhood more ageing-proof and suitable for all age groups, the public space should be accessible. A highly accessible neighbourhood encourages elderly to go out for a walk and this keeps them active and fit. An accessible space for elderly should consist of a safe infrastructure, a well-connected pedestrian network and a legible and clear pedestrian infrastructure.

An accessible public space and being physically active will help vulnerable elderly to be able to cope with heat stress, because this will affect them more often in future with the changing climate. Heat stress is causing more heat-related illnesses and higher excessive mortality rates among elderly. Literature says that to be able to cope with heat stress, we as landscape architects could do a lot and make our cities more thermally comfortable. An urban design can improve thermal comfort if it provides shadow, if it cools the microclimate through evaporation and evapotranspiration and if the design minimises the heat accumulation.

However, the knowledge gap was identified as lack of knowledge on how to design thermally comfortable and accessible residential streets for elderly. The main research questions was therefore formulated as:
MRQ: What design principles can be developed to improve thermal comfort and accessibility for elderly in residential streets?

In order to answer this question, a research through design process is conducted. This is done with the help of two sub research questions:
SRQ1: What design principles make a street thermally comfortable?
SRQ2: What design principles make a street accessible for elderly?

The research through design process resulted in two types of design principles, which were evaluated with the criteria derived from the theoretical framework. Seven design principles to improve the accessibility for elderly and six design principles to improve thermal comfort scored good enough to use them in the next phase for creating integrated design principles. The seven design principles for accessibility score well because they all contribute to a high level of safety. The eliminated design principles did not score well on safety, while this was the most important criterion. Many of the selected design principles were also longitudinal applicable, so throughout a whole neighbourhood. The six selected design principles for thermal comfort are mostly very 'green' solutions and score quite good or average on all three criteria. Most of these design principles are also longitudinal applicable. Both types of design principles also had one design principle that concerned what type of materials should be used. This design principle was considered in the evaluation, but I concluded that the choice of material always is part of the design and can be combined with other design principles. Therefore it can always be part of the integrated design principles even though it did not score very high in the evaluation.
To answer the main research question, the thirteen design principles in total were used to develop and test integrated design principles. The integrated design principles show very green solutions with enough space for elderly, but there is always friction in giving enough space to both interests. What is striking, that it is often possible to combine several design principles. In all design principles, there are at least one but in some even two design principles from thermal comfort combined. These are all longitudinal interventions. Besides that, in each integrated design there are four or five design principles from accessibility combined. Partly they are also longitudinal interventions, but some of them are also single elements, such as the benches and the raised crossings.

It is also notable that the integrated design principles are mainly different when it concerns the used design principles for thermal comfort, but not so much with the design principles for accessibility. Since these design principles can often be used together, it was hard to apply much variation. Therefore, the integrated design principles look a bit of the same concerning the measures for accessibility. A clear example is the zoning of the street. In most integrated design principles this was applied by using green strips to make a clear separation between the street and the sidewalk, and by using different types and colours of materials. The lack of variation and application of most design principles for accessibility in the integrated design principles could be explained by the fact that they are all necessary to create an as much as possible accessible public space for elderly. They complement each other and together they form a very accessible public space. With using only one design principle for accessibility you will not reach an optimal situation. This is different from the design principles for thermal comfort, because often there is only a need for one or two of these principles to make a big difference for the thermal comfort of a public space.

From this research through design process, we can learn that the different design principles improving thermal comfort and accessibility for elderly, can very well be combined. They even complement each other in some situations. A good example is the integrated design that scored the highest, IV (figure ...). The planted tunnel is a very good solution to improve thermal comfort and provides elderly with a pleasant and safe walkway, especially when it is combined with seating and good lighting. This is a design where the needed green space for thermal comfort and the needed space for accessibility are very well balanced.

Figure 38. Integrated design principle IV, scored as the best result.

6.2 Discussion

6.2.1 Reflection on the theory

The choice for the terminology in this thesis has been very decisive in this research. The term 'accessibility' could easily been replaced by terms such as 'walkability' or 'attractiveness'. Also social factors and the availability of facilities are of big importance for elderly and could also have been included in the terminology (Arnberger et al., 2016). Walkability indicates how friendly a neighbourhood is to walking. It means that the built environment is giving comfort, safety and provides aesthetic appeal (Boeijen, 2016). Attractiveness is often mentioned in literature and it has been shown that people are more likely to walk in an attractive neighbourhood (Prins et al., 2016; Thompson, 2013; Michael et al., 2006). However, aesthetic appeal and attractiveness are terms that also include personal preferences and experiences. It is much harder to define measures that contribute to aesthetics and attractiveness because this differs per person. To research this you need a participatory study or questionnaire. It also differs per neighbourhood, per site. Accessibility is a term that can be approached very technical. It kept the research small and very 'to the point'. The design principles are applicable at every site. However, if the research was conducted with other terminology, the solutions would have looked differently. Also thermal comfort was a specific topic within the field of climate change. This was chosen because there are very clear numbers and many studies that show the relation between negative health outcomes for elderly and heat stress. However, there are also studies that show the relation between bad or cold weather circumstances and the effect on elderly. This would have resulted in a totally different research.

Likewise, the choice of terminology for the criteria was very decisive as well and the research would have turned out differently if these were other terms. The literature was not unambiguous about what accessibility means and which aspects should be taken into account. Many different characteristics that contribute to an accessible public space were mentioned and this led to a categorisation with three main criteria: safety, connectivity and legibility. The choice for these three criteria did not always appear to be the easiest, because while evaluating the design principles it became clear that especially the criteria connectivity and legibility led to some difficulties and confusion. In literature, connectivity was often also explained on a bigger scale, of a whole neighbourhood. The lay-out of a neighbourhood contributes to the amount of connectivity, for instance when it has no dead-end streets and small block sizes (Pearce & Maddison, 2011). Also the availability of public transport makes a neighbourhood better connected (Moran et al., 2014). However, this was something I could not influence in my research. My research took place on a smaller scale. Besides that, while evaluating the design principles it became clear that the difference between some criteria were not so sharp. An example is the relation between connectivity and legibility. When a design principle contributes to a higher connectivity in a neighbourhood, it could also contribute to legibility, because elderly would not easily lose their way. This is a constant consideration to which criteria something 'belongs'. The same happened a few times between minimising heat accumulation and providing shadow. Some design principles provide a lot of shade, so it scores very well on this criterion, but at the same time the shade ensures also less heat accumulation. It was also difficult to estimate the actual effect a design principle would have on minimising the heat accumulation or cooling the microclimate by evaporation or evapotranspiration. The effect of shade is more easy, because you can simulate the shade in a 3D model. So for this research, I had to assume that for instance a row of trees contributes to cooling by evapotranspiration.

6.2.2 Reflection on the RTD process and results

The research through design process was an iterative process from designing, testing and evaluating. Pragmatic solutions had to be considered, while designing is also a creative process based on intuition. Therefore it was very important to make the evaluation of the designs as transparent and concrete as possible and that is what was done with the criteria matrices. As a designer, of course you have a personal preference but that should not be leading. Therefore it is very important to make the criteria as explicit as possible. As mentioned in the previous subchapter 6.2.1, this was not always so easy. Some criteria could overlap in some cases. This resulted sometimes in scoring a design principle more or less the same on two criteria. The evaluation of the design principles was not easy in general. Unfortunately I could not use a group of participating elderly. The evaluation of all design principles is 'an educated guess' based on literature and examples from practice. Every design principle was given a grade for each criteria. This was done by comparing the design principles on each criterion separately with each other and rate them. The best would get the highest grade for this criterion, the worst would get the lowest grade. However, this is still a subjective way of evaluating. If somebody else would have done this evaluation, the result might have been differently. Besides that, the final results show that the top three integrated design principles have very similar scores. There is not much difference between them, so this indicates the subjectivity and the fact that the result could be different if someone else would have evaluated.

6.2.3 Limitations of the research

Because of time constraints, there was no participatory research included in this thesis. It would have made the research stronger if elderly would have given their opinions and suggestions for design ideas, and also help evaluating the design principles. I contacted the elderly home in Carnisse and talked to some elderly, but unfortunately the management of the home was not willing to help me.

The only 'participant' who helped me, was my own grandfather, who is 95 years old and still walking to the supermarket every day. He told me about the daily struggles and showed me what happened when he fell over with his rollator. We discussed the design principles for accessibility and he made some suggestions.

During the site visit and the accessibility analysis in Carnisse, some observations and small talk were made with elderly on the street. This gave some insights and new ideas. However, this was of such a small scale that this could hardly being used as part of my research.

The choice of the study area which would help me identify the test beds, was also a bit of discussion. It was hard to make a choice which neighbourhood was suitable for the research, because the neighbourhood should have problems with heat and with lacking accessibility. To identify problems with accessibility, you really need to dive deep into a neighbourhood, because this happens at such a small scale. When the design contest of 'Who Cares?' came along, this was an opportunity to search for starting points in Carnisse. According to the maps of van der Hoeven and Wandl (2015) and research of the municipality of Rotterdam, Carnisse seemed to be a good candidate. When I decided to use Carnisse as my study area and conducted the analyses there, I came to the conclusion that the problematic streets concerning thermal comfort and accessibility were not matching. This put me for a challenge: I needed to identify two different test beds, one for thermal comfort design principles and one for accessibility design principles. The situation asked for some improvisation and I needed to change the research process a bit. You could discuss that the choice for Carnisse was not the best one and it took a lot of time to make it work.

6.2.4 Societal and scientific relevance

With this research I stressed the importance of thermally comfortable and accessible spaces for elderly. If we look at the future climate scenarios and the expected number of elderly in our society, it is very important that we now start with adapting our public spaces. If we don't do this, there will be more striking numbers of people suffering from extreme heat in the city. The changing urban climate is affecting the daily lives of all vulnerable people. Therefore, it is good to explore design solutions for this worldwide problem. It is important to show people from municipalities, landscape architects and urban designers which design principles could be used in neighbourhoods that suffer from heat island effects and need improvements in making the streets aging-proof.

The research is based on different theories on how to establish accessibility for elderly and thermal comfort in residential streets. The research through design process showed many possibilities how to use these theories and answer the design question. It is a step towards more climate responsive design with a focus on vulnerable groups in our society. This research shows that designs can very well be both thermally comfortable and also improve the accessibility for elderly.

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