COOL RETAIL

Towards novel, climate-resilient shopping streets

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MSc Thesis Landscape Architecture
Wageningen University
April 2022

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Document information

Course: MSc thesis Landscape Architecture

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In commission of

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Date

25 April 2022

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PREFACE

This thesis marks the conclusion of my journey through the bachelor and master programs of Landscape Architecture at Wageningen University. I am pleased to be able to reflect on a master thesis period that has been very enjoyable. After starting the process in September with a lot of passion and enthusiasm, I am still as excited about climate-resilient design as when I started, if not more. For a long time, I have felt as though climate resilience has not been high enough up on the agenda of urban designers and policy makers. The COVID-19 pandemic illustrated for me how important greenery in our vicinity is. I hope to inspire many people into considering climate-resilient solutions for our cities and hope to pursue a career in which I can continue to inspire many more people.

I would very much like to thank my supervisor Joao, for his continuous enthusiasm and passion, ever since the Climate-responsive Planning and Design course. That course kickstarted my passion for climate resilience that led to the writing of this thesis. As the methodology within this thesis is founded upon participatory sessions, I am grateful for the shop owners of Amersfoort that were willing to discuss my design propositions. Finally, I would like to thank everyone who expressed their enthusiasm for the scope of my thesis and the many fruitful discussions it led to. As for the thesis room in Gaia, I could not have done it without my fellow students and friends.

ABSTRACT

The main character of many streets in Dutch city cores is that of a shopping street. Shopping streets are vulnerable, in relation to urban microclimatic problems, leading to heat stress and flood risk. Moreover, a lack of thermal comfort threatens health and well-being and makes people underuse or even avoid shopping streets. Therefore, climate-resilient shopping streets are needed. However, there are tensions between climate-resilient interventions and retail functionality. This thesis aims to design novel, climate-resilient shopping streets that embrace synergies between climate resilience and retail functionality and cater to the different actors within the public space of shopping streets.

This thesis answers the following main research question: How can Dutch shopping streets be made climate-resilient in a way accepted by shop owners? This thesis provides an inventory of 18 possible climate-resilient interventions for shopping streets. Moreover, participatory sessions with shop owners led to the evaluation of each climate-resilient intervention regarding its synergy with retail functionality. Climate-resilient interventions not only work alongside the retention of retail functionality, but they can even enhance the overall shopping experience. Lastly, by raising awareness of climate issues in shopping streets, taking shop owners along in the design process and adhering to the design criteria that were derived from the participation sessions as presented in this thesis, the acceptance of shop owners towards climate-resilient interventions can be obtained and even be improved. This thesis provides practice-orientated design guidelines for potential implementation of climate-resilient interventions in shopping streets. The use of a digital microclimate quantification toolbox with limited calculations and a small sample size in the participatory sessions causes limitations within the outcomes of this thesis. Future research is needed to tackle these limitations and research a broader perspective of the role of climate-resilient shopping streets within the larger system of the city.

To conclude, this thesis demonstrates that complex, compact Dutch city centres that largely consist of shopping streets, can be made climate-resilient whilst retaining and even enhancing the possibilities that shopping streets offer for shop owners and their customers.

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1. INTRODUCTION

1.1. The climatic discrepancy within cities

July 2019. It is an extremely hot, summer period in the Netherlands. The corresponding situation in Dutch cities is illustrative of a climatic discrepancy within cities. On the edge of the city, in one of its outdoor swimming pools in a forested setting; rich in green, many people are packed together (RTV Utrecht, 2019). In the city centre, however, shops are forced to close down their establishments due to the heat holding back customers and threatening product quality. One shop owner explains: *"er komt ook gewoon geen mens in de stad – wat wij allemaal heel goed begrijpen"* [there is simply no one coming to the city centre – which we all understand very well] (van Kommer, 2019). Two public spaces within the city during a heatwave, with a large discrepancy in their attendance, as illustrated in Figures 1 and 2.

1.2. Urban climate and city centres

The introductory story is illustrative of a worldwide phenomenon. More and more people are drawn to cities and city centres.

Figure 1: "Peak attendance at outdoor swimming pools": Several outdoor swimming pools in forested settings experience large crowds. Source: RTV Utrecht (2019).

Figure 2: "These café-restaurant owners shut up shop early or completely due to the heat": An extreme heat event caused café-restaurant owners in Amersfoort to close their establishments. Source: van Kommer (2019).

The paved, central parts of the city prove to become warmer during hot, summer days than the surrounding non-urban areas. As a result, heat that builds up during the day, is trapped in the city and sustains heat stress throughout the night (Deilami, Kamruzzaman and Liu, 2018; Thorsson et al., 2010). This phenomenon is known as the Urban Heat Island effect. As a result of climate change, city centres in particular will only become warmer, sustain more heat stress and experience more extreme rain events (Pötz, 2016). The Urban Heat Island effect in cities worsens with climate change, thus negatively affecting the urban climate. The urban climate is founded on the physical characteristics and the energy consumption of cities. Height of buildings, soil sealing, limited vegetated surfaces, combustion engines, heat release from air conditioning and air pollution are all features of urban areas that cause urban areas to retain up to twice as much heat as the surrounding non-urban areas. Therefore, urban areas are described to have a different climate than the surrounding non-urban areas (Emilsson, 2021).

An urban climate within city centres that is perceived as pleasant is very relevant, as city centres hold a relatively high number of residents per km2 (Lemonsu et al., 2015). City centres are amongst the areas with the highest PET (Physiological Equivalent Temperature) and the highest risks of nuisance from extreme rain events, when comparing the city centre to for example adjacent suburbs or surrounding countryside (Stichting CAS, 2021). Higher temperatures cause higher mortality rates and threaten the overall health, well-being and labour productivity of people. Not only are these risks dangerous for people in general, but they are even more dangerous for vulnerable people with existing health issues (Pötz, 2016). Moreover, the durability of urban infrastructures, such as pavement, is under pressure during extreme heat. The same goes for the durability of natural elements, as well as green spaces having to deal with the increased pressure of many visitors (Kluck et al., 2020). As a result of heat, more indoor cooling is needed, increasing energy consumption. More water is needed for cooling as well, whilst green areas need more irrigation. Rainwater and surface water that is heated up, has a higher chance of developing undesirable algae and bacteria. In general, the urban water cycle is vulnerable. On the one hand, the sewage system struggles to deal with discharging during an extreme rain event, whilst on the other hand, this discharged water could be vital during a period of drought. Therefore, a more circular water cycle is desired, which can deal with larger peaks of rain in a short time, whilst providing irrigation for urban greenery (Pötz, 2016). Overall, climate-resilient interventions are very much needed.

When we focus on cities in the Netherlands, we see that city centres are often built up in a compact urban morphology (Vries et al., 2017). Compact urban morphologies are prone to trapping radiation and limiting ventilation, which can heat the streetscape (Thorsson et al., 2010). Moreover, these city centres are prone to soil sealing. This is a phenomenon where the natural soil surfaces are covered in impermeable surfaces, resulting in flood risk during extreme rain events and fragmented natural areas (Galderisi and Trecozzi, 2017). Within the compactness of city centres, problems regarding heat arise. The MRT of squares can be 20 °C higher than an adjacent narrow street canyon. This is due to the large amount of radiation that can reach and warm up the surface area of the square. Narrow street canyons generally have more shade, preventing this effect. However, when the sun reaches a point in the day where it can light up a narrow street canyon, this street can warm up to be 8,6 °C warmer than the same aforementioned square. This is due to the multiple reflections of short- and longwave radiation in between the facades that flank the narrow street (Thorsson et al., 2010).

1.3. The dominance of shopping streets in Dutch, city centres

The main character of many streets in Dutch city cores is that of a shopping street. Retail, restaurants and cafés draw in many people. A preliminary analysis of ten cities in the Netherlands, performed by the author, showed that around 53 % of the streets within the city core can be characterised as shopping streets. The included Dutch cities covered a wide range of scale, ranging from 50000 residents to an extend of 200000 residents. Whilst the core of a city also consists of non-commercial streets, the scope of this thesis is the shopping street. Here, the friction between climate-resilient interventions and retail requires attention. Within the shopping streets, four typologies can be distinguished. Most common is the narrow street, covering 27 % of all streets in the city core. These streets have a width of up to 7,5 m. Moreover, there is the wide street typology, covering 15 % of all streets in the city core. These streets have a width ranging from 7,5 m to 13,5 m. A third typology is the crossing between narrow and wide streets, covering 3 % of all streets in the city core. These areas cover around 60 m2 to 240 m2. Lastly, there are the crossings on squares. They cover 8 % of all streets in the city core. The area of squares ranges from around 700 m2 to 9200 m2. A complete overview of this preliminary analysis can be found in the appendix.

1.4. The shift in shopping streets

A CityTraffic analysis by Meinders (2019) showed that during an extended period of warm weather in the Netherlands in 2018, fewer people visited shopping streets, as they preferred to visit, among other things, recreational areas. Additionally, Dutch shopping streets, which are largely paved and exposed to the elements, are not ready for more prolonged heat waves and extreme rain events.

Shopping streets are vulnerable, in relation to the urban microclimatic problems in compact city centres as mentioned earlier. Shopping streets are characterised by their open and exposed character, with lack of greenery and largely paved surfaces. Therefore, they offer little to no protection from high temperatures and extreme rain events (Bourbia & Boucheriba, 2010). Referring back to the four shopping street typologies, the wide street and crossings are very much exposed to the sun and warm up easily. The narrow streets offer a little more protection, until the solar radiation finally reaches the street, heating the surfaces rapidly. When the MRT (Mean Radiant Temperature) of shopping streets rises, the thermal comfort decreases. In other words, heat stress occurs. Studies show that a lack of thermal comfort makes people underuse or even avoid public spaces (Lenzholzer, 2012). This was illustrated by the newspaper article in Figure 2, as previously highlighted in the introductory story. It describes how café-restaurant owners in Amersfoort closed their establishments due to an extreme heat event.

This ties in with an article by Martínez-de-Albéniz and Belkaid (2020), who describe how a lack of thermal comfort negatively affects shop sales. In contrast, a study by Wolf (2005) showed that longer visits to shopping streets were associated with these streets having trees, as opposed to shopping streets having no trees. Moreover, the same study showed that, when standardised across convenience, shopping and speciality goods, consumers on average value products between 9 % and 12 % higher in streetscapes with trees than in streetscapes without trees. Finally, the study showed that: “the most highly preferred business streetscapes have [survey] ratings that compare with those of forested and outdoor recreation settings” (Wolf, 2005, p.398). Thus, people are in favour of greenery in shopping streets, which many Dutch shopping streets currently do not have.

In general, Dutch shopping streets are under pressure. They cope with vacancy: an increasing percentage of shops are unoccupied (PBL, 2020). Many studies predict a change for shopping streets. Shopping will be more of a hybrid concept, where online shopping will further take over as the convenient way to get hold of products. Offline shopping, physically visiting a shop, will be about expertise and experiences (Stieninger et al., 2021). Shops will require fewer square metres, as they need a smaller stock of products, and will be a social hub: to discuss, experience and test products (Bjerre, 2018). Physical shops will offer scarce things in a digital world: human interaction, natural elements and things and activities that can be experienced with all five senses (Poleg, 2020).

1.5. Problem statement

Kluck et al. (2020) describe that for municipalities, it is unclear which interventions should be implemented in public spaces to benefit climate resilience, especially in spaces where many other uses of space need to be considered, as is the case in shopping streets. Additionally, there is a limited amount of research on the relation between climate-resilient design and shopping streets.

Wolf (2005) describes:

> *"Issues of urban forest extent and health may not be of high priority to certain urban stakeholders such as merchants and retailers. Although retailing research has probed to great extent how shoppers react to the elements of store interiors, few marketing studies have considered the influence of the outdoor retail environment"* (Wolf, 2005, p. 400).

Moreover, there are tensions between climate-resilient interventions and retail functionality. Amongst retail functionality, several users of shopping streets, such as shop owners, shop suppliers and the shopping public, all have different desires for the way they can use public space. These users are illusrated in Figures 3 to 6. To make shopping streets climate-resilient, the tensions in the shopping street revolving around the implementation of climate-resilient interventions and retail functionality need to be tackled. Moreover, shopping streets not only have to deal with today's climate, but also with climate change in the future.

Thus, to make shopping streets resilient regarding the urban climate and the future of retail, additional knowledge is needed. Firstly, there is a lack of knowledge on the possible interventions that are applicable in shopping streets to make them climate-resilient. Secondly, the possible synergies between these climate-resilient interventions and the retail function of shopping streets must be researched. Lastly, shop owners play a large role in shopping streets. Working out what their acceptance of interventions is, is needed to prevent NIMBY-like opposition. NIMBY (not-in-my-back-yard) is commonly referred to in the field of renewable energy, but generally describes the discrepancy between the public support for interventions at a national level and opposition to the implementation of these interventions at a site-specific, local level (Petrova, 2016). Shop owners are chosen as the target group within this thesis, as they are very knowledgeable about what goes on and is needed within the shopping street.

Figure 3: vans and trucks of shop suppliers (Hensel, 2018).

Figure 4: shopping public (Broekhuizen, 2019).

Figure 5: exposed shopping street in Amersfoort. Adapted from Funda (n.d.).

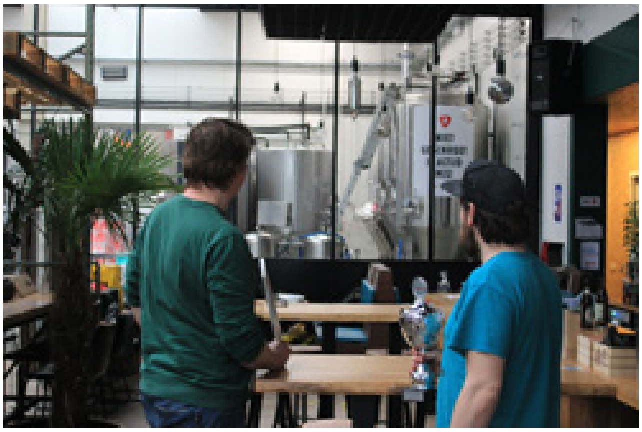

Figure 6: shop owners (Pels, 2021).

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2. THESIS STATEMENT

2.1. Objective

This thesis aims to design novel, climate-resilient shopping streets that embrace synergies between climate resilience and retail functionality and cater to the different actors within the public space of shopping streets. These objectives are addressed in reference to the KNMI climate scenario W(H), which will be elaborated upon in chapter 2.3.3.

2.2. Research questions

This thesis aims to answer the following main research question:

Main research question (MRQ):

How can Dutch shopping streets be made climate-resilient in a way accepted by shop owners?

To answer the main research question, three sub-research questions have been formulated:

Sub-research question 1 (SRQ1):

What are possible interventions to make Dutch shopping streets climate-resilient towards the W(H) climate scenario?

Sub-research question 2 (SRQ2):

What are the synergies and trade-offs between retail and climate resilience?

Sub-research question 3 (SRQ3):

What is the current acceptance of shop owners towards climate-resilient interventions and how can this be improved?

SRQ1 was aimed at determining the range of design intervention possibilities. SRQ2 gives an idea of the synergies that these design possibilities could offer, therefore applying the intervention possibilities to the functions of the shopping street that this thesis mainly focuses on: retail and climate resilience. SRQ3 takes the final design possibilities to an actual site, where shop owners will be involved to assess the possibilities. This has informed a final, integrated design, that in turn developed knowledge towards an answer to the main research question. The research questions will be further elaborated upon in chapter 3: Methods and materials.

2.3. Theoretical framework

Within this thesis, three main concepts are relevant to define and operationalise to perform the research in this thesis. These concepts are shopping streets in compact, Dutch city centres, climate-resilient design and participatory design.

2.3.1. Shopping streets in compact, Dutch city centres

Dutch city centres are generally built-up in a similar manner. The eldest part of the city is usually the core of the city. A strongly densified centre forms the core: the former military stronghold of the city in medieval times. This core is surrounded by layers of younger expansions. The earliest expansions formed additional rings around the core, in times when the city was still being developed as a military stronghold (Vries et al., 2017).

Within the compact Dutch city centre, a considerable part of the urban infrastructure can be characterised as a shopping street. "Shopping streets are simultaneously a site of social, economic, and cultural exchange. Despite their standardized architectural designs and transnational ownerships, they provide a "face" of local social and cultural identity" (Zukin, 2012, p.282). "The main shopping streets tend to serve the whole city. The offered main items are fashion or leisure related. Individual shops and larger chain stores are located [on] these streets. In many cities, these streets are mostly pedestrian based. These shopping areas are mostly located in the historic city centre because the urban grid is denser and [finer] grained in these areas than in other modern urban areas" (van Nes, 2005, p.182). The Dutch shopping street is characterized by a uniform design that often uses the same formula, where shopping is the main function. The streets form a network with the busiest street as the spine and connected side streets and squares (Hospers, 2016). Shopping streets can be further categorised into four typologies: the wide shopping street, the narrow shopping street, crossings of wide and narrow shopping streets and crossings on squares. This is in line with an existing study by Buro Poelmans Reesink Landschapsarchitectuur, Le Far West and Willem Jakobs (2017). Each typology can be analysed through landscape analysis to determine the dominant functions, traffic distribution and performance regarding climate resilience.

2.3.2. Climate-resilient design

The relation between climate and design is intensively described in the literature. "Climate-sensitive urban design offers a sustainable solution to urban overheating. It involves a combination of innovative choices including urban fabric, urban morphology, and re-integration of urban green and blue infrastructures" (Liu et al., 2021, p.1). Resilience is a term that is often used when speaking of design for the urban climate. Climate-resilient design is aimed at dealing with climate impact and disturbances and is measured in terms of the ability to persist through change (Meerow and Stults, 2016). Climate-resilient design is an overarching concept, with several deviating definitions and characteristics floating around in the academic realm. Meerow and Stults (2016) performed a study through an extensive literature review, to see how the concept 'climate-resilient design' is used and defined in the literature. They found a key difference, which therefore needs to be clearly defined in the theoretical framework of this thesis.

Some literature refers to resilience as the ability to bounce back, whilst others extended this definition to the ability to adapt, improve and thrive, also referred to as 'bouncing forward'. The latter definition sees climate impact as an opportunity to transform the current system into a novel adaptation (Meerow and Stults, 2016). Bouncing forward is a very relevant definition within this thesis as: "considerable investment is made in sustaining the performance of particular structures in the face of possible short-term episodic shocks (...) However, where the focus shifts to structural transitions in the face of long-term secular stress, as with many sustainability threats, many of these measures can have the effect of inhibiting adaptability and transformability" (Smith and Stirling, 2010, pp.5-6).

Therefore, climate-resilient design should be aimed at the ability of both bouncing back and bouncing forward, as emphasised by Folke et al. (2010): “adaptation and transformation [are] essential to maintain resilience (…) the very dynamics between periods of abrupt and gradual change and the capacity to adapt and transform for persistence are at the core of resilience” (Folke et al. 2010, p.2).

“Resilience is shown to support more transformative inclusive and dynamic approaches to designing urban systems” (Brown, 2013, p.114). This highlights that resilience as a concept is developing into a concept that both supports bouncing back and bouncing forward as its key components. To conclude, a climate-resilient design is defined as a combination of sustainable design solutions to urban overheating, which can deal with climate impact and disturbances, as well as facilitate adaptation and transformation for the long term.

2.3.3. Climate scenario W(H) for 2050

As climate-resilient design is about dealing with change, and climate change in particular, it is important to define what climate change entails in the context of this thesis. Prolonged periods of warm weather are not a coincidence in the Netherlands. As a result of climate change, these periods will only become more frequent. For this thesis, the KNMI climate scenarios are used as a prediction for the future climate in the Netherlands. In particular, the W(H) scenario for 2050 is used, which is the scenario that predicts the largest change in the Dutch climate for 2050 (KNMI, 2014). Scenario W(H) is chosen because a final design that can tackle this scenario, can also tackle the scenarios that predict a smaller change in the Dutch climate. Therefore, the need for designing for the other scenarios is eliminated and time consumption is limited.

In scenario W(H), there are some significant changes regarding heat in the Netherlands. The number of days with a maximum temperature of above 30 °C, will increase from four to thirteen days in 2050, increasing the chance and severity of heat stress. The same goes for the number of days with a maximum temperature above 25 °C, increasing from 26 to 47 days (Stichting CAS, 2021). However, heat is not the only factor that is expected to have an increased effect on our living environment. Extreme rain events will become more frequent as well. Rain events that now occur once in 10 years, will occur twice every 10 years in 2050. The same pattern is visible in rain events that occur once every 100 years, which will be 2.4x more frequent in 2050 compared to now. In general, cities are especially vulnerable to the changing climate, regarding both heat and extreme rain (Stichting CAS, 2021). To determine whether a design is climate-resilient and able to deal with climate scenario W(H), two main indicators are used in this thesis.

2.3.4. Heat stress

Heat stress is the first indicator of climate resilience. Heat stress can be measured in Physiological Equivalent Temperature (PET), in degrees Celsius (°C). The higher the PET (°C), the higher the experienced heat stress is (Thorsson et al., 2010). Matzarakis et al. (1999) made a table relating PET to the grade of physiological stress. The original table ranges from a PET of <4°C to 41>°C and a grade of physiological stress ranging from extreme cold stress to extreme heat stress. As can be seen in Figure 7, Nouri et al. (2018) later developed this table into a new variation, in which the extreme heat stress category was further extended into four levels, covering higher PET’s (°C). As this thesis deals with extreme heat in a scenario for 2050, the wider range of physiological stress categories of Nouri et al. (2018) was needed to categorise all PET measurements.

PET (°C)	Grade of physiological stress
<18	Slight cold stress
18-23	No thermal stress
23-29	Slight heat stress
29-35	Moderate heat stress
35-41	Strong heat stress
41-46	Extreme heat stress (LV1)
46-51	Extreme heat stress (LV2)
51-56	Extreme heat stress (LV3)
>56	Extreme heat stress (LV4)

Figure 7: Ranges of PET and gradation in physiological stress. Source: After Nouri et al. (2018); adapted from Matzarakis et al. (1999).

PET can be assessed through qualitative research: an expert-judgement approach, and quantitative research: using digital microclimate quantification tools (Liu et al., 2021). The ‘Climate-proof City Toolbox’ was used as a digital microclimate quantification tool, which can calculate the difference in PET in a study area after drawing in climate-resilient interventions within the tool. The result is a PET map of the current and new situation. The ‘Climate-proof City Toolbox’ offers an easy-to-use interface and relatively quick calculations, therefore fitting into the limited time frame of this thesis.

> *“The toolbox can be used to explore possible measures for a project area. For example, with the CRC Toolbox, various plan alternatives (scenarios) can be quickly drawn up, compared with each other and compared with previously set adaptation goals (…) The CRC Toolbox contains 40 adaptation measures from which users can choose. The information in the CRC Toolbox is based on proven properties and performance of the measures, tailored to the Dutch climate”* (Brolsma, 2021).

However, it has to be noted that the toolbox has certain limitations, which are discussed in the discussion chapter.

2.3.5. Rainwater infiltration capacity

Rainwater infiltration capacity is the second indicator of climate resilience. It can be defined as the extent to which an area can detain rainwater and control superficial runoff. Sufficient rainwater infiltration capacity prevents pluvial flooding (Galderisi and Treccozzi, 2017). Rainwater infiltration capacity can be determined through land-use analysis: determining the permeable surface percentage and establishing soil type. Rainwater infiltration capacity can also be determined through digital microclimate quantification tools, such as the ’Climate-proof City Toolbox’.

2.3.6. Participatory design

An important aspect of this thesis is the participation of shop owners. First of all: “In a participatory design process, ideas of what is good (values), useful (functions), and beautiful (aesthetics) are made durable in inscriptions in the design, such as choices in materials, options for use, color use, flexibility, etc” (van der Velden and Mörtberg, 2014, p.11). Thus: “Involving future users as co-designers in the design process significantly increases the chance that the product represents the values and meaning of the future users” (van der Velden and Mörtberg, 2014, p.3).

There are several types of co-design or participatory design. Lee (2008) describes three modes of participation, as can be seen in Figure 8. In particular, the importance of “more collaboration between designers, researchers and users/people between different modes of participation” is stressed (Lee, 2008, p.36).

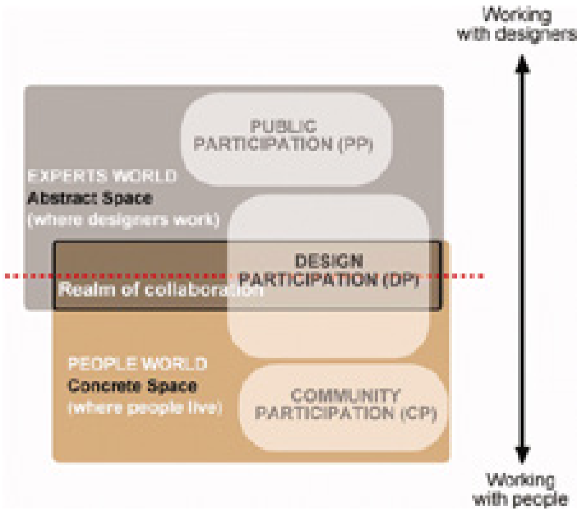


Figure 8: Three modes of participation according to Lee (2008).

The realm of collaboration within the design participation mode is where experts and users can benefit from each other. To make design participation as fruitful as possible, designers should take on different roles. As a designer, you should develop the participation process, facilitate relevant subject and design knowledge, as well as generate new design iterations (Lee, 2008).

Wojewska, Singh and Hansen (2021) stress the importance of defining and analysing the target group that is concerned regarding proposed climate adaptive measures.

> *"By understanding the factors that influence an individual's participation decision in targeted populations, policy makers will be better able to address (potential) participants' needs, explicitly accommodating their interests in project design, all the while enhancing the effectiveness of the project through the provision of tailored incentives."* (Wojewska, Singh and Hansen, 2021, p.5)

In other words, by involving shop owners in several steps of the design process, the final design can offer a better fit to their requirements for a well-functioning shopping street, whilst also addressing problems that threaten its climate resilience. Wojewska, Singh and Hansen (2021) propose the use of a conceptual framework to trace how extrinsic and intrinsic factors influence the decision of participants to participate in design processes for climate adaptation, as shown in Figure 9.

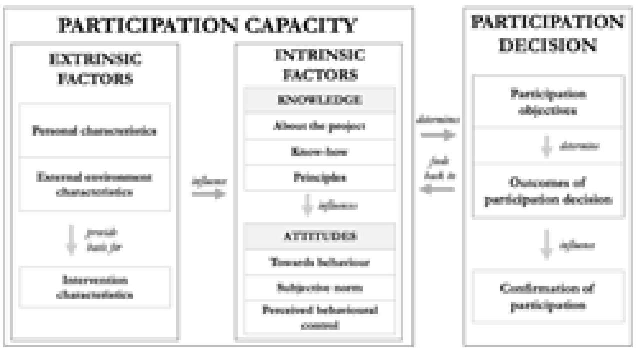


Figure 9: The participation capacity framework. Source: Wojewska, Singh and Hansen (2021).

By understanding the target group, in this thesis shop owners in the city centre of Amersfoort, the interviews and design proposals can be tailored to their participation capacity. In practice, the interviews have to contain questions to get an understanding of the knowledge of shop owners on climate resilience interventions, climate-related problems in shopping streets and the effect of climate-related problems on retail. Moreover, the design proposals have to fit external environmental characteristics such as the urban microclimate, the history of the city centre and the shopping function of the city centre.

Presenting visualisations of potential ideas plays an important role in this thesis. To test these design proposals with shop owners, it is important to think about the theory behind developing scenario visualisations. Tress and Tress (2003) stress several important criteria that visualisations used in stakeholder participation should adhere to. When involving non-experts (in this thesis concerning urban microclimatic design), small-scale visualisations are most appropriate. They portray the site in a very realistic and detailed manner. Furthermore, photorealistic visualisations based on real-life images offer both easy accessibility and an accurate projection of reality. "A higher degree of abstraction leaves an empty, unknown area that is filled by people's imagination, which could easily lead to misinterpretations and consequently complicate communication." (Tress and Tress, 2003, p.164). By adhering to these criteria, the visualisations will be easily identifiable and interpretable for stakeholders, in this thesis shop owners in the city centre of Amersfoort (Tress and Tress, 2003).

Additionally, to the aforementioned factors, it is important to think about the way an optimal engagement of participants can be achieved. Reed et al. (2017) propose a theory of participation to explain variation in engagement for public participation. This phenomenon is described through four groups of factors, as can be seen in Figure 10. First of all, the context of participation is important. By approaching participants in a way that engages their interest, as well as proposing a process that fits their resources in terms of time and knowledge, participation is more likely to succeed. Secondly, the participation process design needs to allow for transparency and the possibility of input of participants, rather than solely presenting a fixed idea. This ties in with the third domain, power, which stresses that all participants should have an equal input within the participation process. Lastly, the participation process should fit the temporal and spatial scale of the participants. In terms of shop owners in Amersfoort, the participation process should therefore focus on the shopping streets that they experience daily, as well as on the short-term effects of potential interventions.

By adhering to these four groups of factors, the participation process becomes as relevant and accessible to the participants as possible, therefore offering the highest participation rates, levels of engagement and likelihood of useable outcomes (Reed et al., 2017)

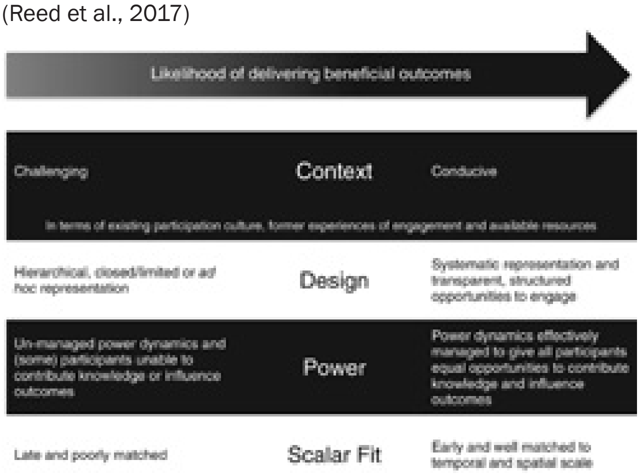


Figure 10: A theory of participation that explains how the outcomes of stakeholder and public engagement in environmental management are explained by context, process design, the management of power dynamics, and scalar fit. Source: Reed et al. (2017).

3

3. METHODS AND MATERIALS

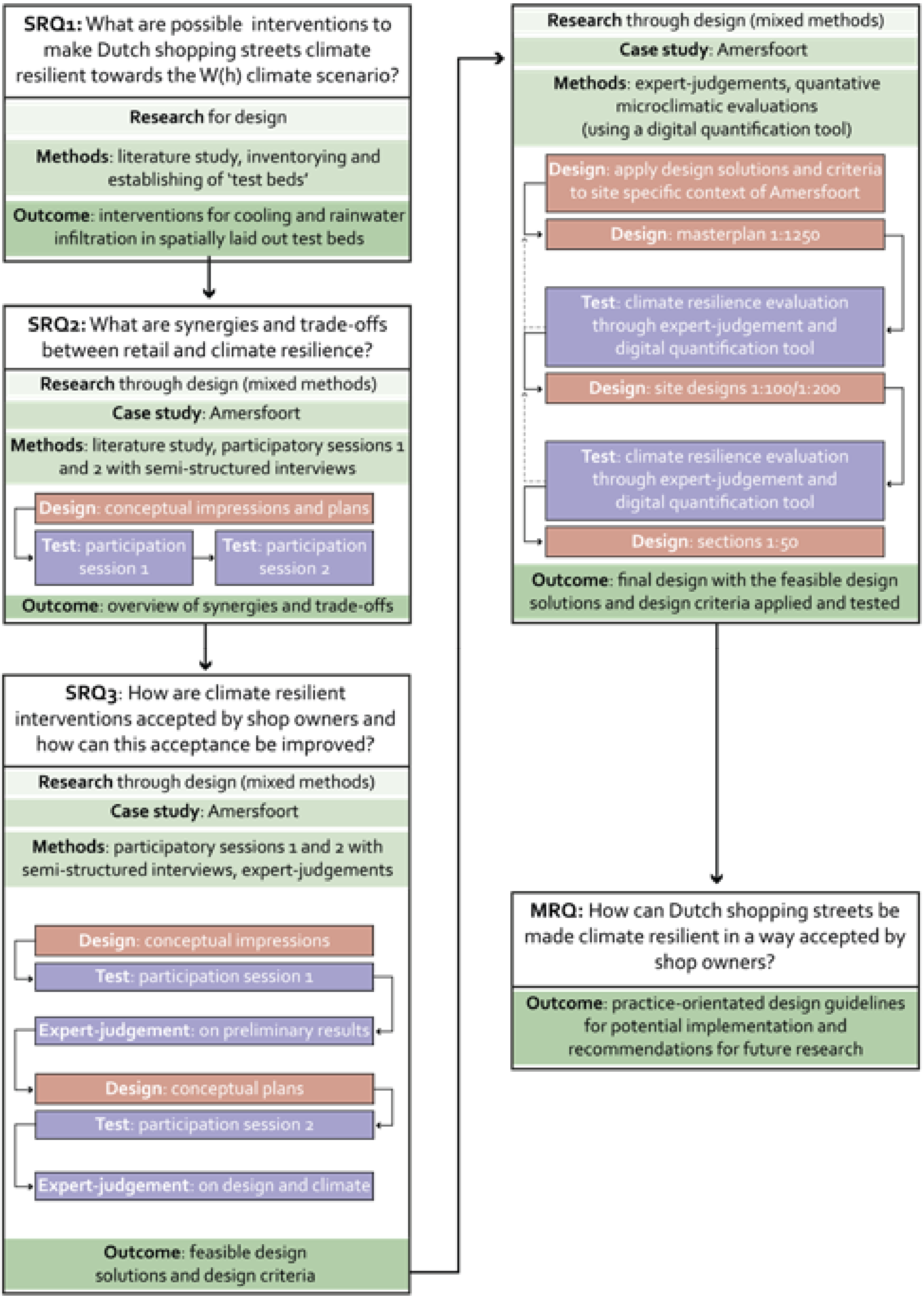


Figure 11: the methodology followed in this thesis

The methodology employed in this thesis, as can be seen in Figure 11, indicates the methods, the flow of information and expected outcomes. By answering each sub-research question and implementing this knowledge into the final design, the main research question (MRQ) is answered. In the following section, each step of the methodology is elaborated upon.

SRQ1 is answered with Research for Design. Thus, the research outcomes inform the design process (van den Brink et al., 2017). This is where inventorying of possible climate-resilient interventions takes place, through a literature study.

SRQ2 is answered through a Research through Design (RTD) method. Here, designing is actively employed to generate new knowledge. Specifically, a mixed-methods RTD is used. Constructivist RTD is applied to take aesthetics into account, using expert judgement. By including shop owners in semi-structured interviews in participatory sessions, a transformative RTD is applied. "Such research is oriented on co-creation and co-ownership of knowledge and process" (van den Brink et al., 2017, p.59). "Design guidelines, spatial prototypes or other generalisable design knowledge will have to include various aspects [through various RTD methods] to make it usable, design-relevant knowledge" (van den Brink et al., 2017, p.61). In SRQ2, the transformative RTD focuses on gaining knowledge through presenting visualisations of climate-resilient design for a shopping street to shop owners of Amersfoort. Shop owners are chosen as the target group for the participation sessions in this thesis. Using one target group limits the time and resources needed, whilst shop owners know many different aspects of the shopping street. This is further elaborated upon in the discussion chapter.

In *participation session 1*, semi-structured interviews provide knowledge on the potential and problems of climate-resilient interventions concerning retail functionality. To achieve this, small-scale, quasi-photorealistic visualisations of climate-resilient shopping streets in Amersfoort are presented. One visualisation is made per shopping street typology, resulting in four visualisations overall. They provide a level of detail that makes the portrayed location recognisable and offers little abstraction, which prevents misinterpretation of the proposed design (Tress and Tress, 2003).

SRQ3 is also answered through a Research through Design method. Again, constructivist RTD is applied to study aesthetics in the designs, using expert judgement. Transformative RTD focuses on participation. Here, *participation session 1* is used to draw preliminary conclusions on important design criteria that a climate-resilient shopping street should adhere to.

The results of *participation session 1* inform a new design iteration, which is tested in *participation session 2*. Here, a site design plan is shown for each shopping street typology, enabling the showcase of more detail and a precise scale of interventions. This results in four site design plans overall. Again, knowledge on the potential and problems of a design for climate resilience shopping streets concerning retail functionality are generated. Moreover, it informs a final revision of the generated design criteria from *participation session 1*.

The results of *SRQ1, 2 and 3* inform a design for the shopping streets in the city centre of Amersfoort, which is tested through expert judgements with an expert on urban microclimatic design and a microclimatic quantification tool.

Finally, the *MRQ* is answered, where the acquired knowledge of *SRQs 1, 2 and 3* informs a discussion and conclusion chapter.

3.1. The study area: Amersfoort, the Netherlands

To answer the research questions, a study area was used. The study area was used to study a complex phenomenon in a real-world context (Yin, 2014). It is a purposive sample, because the characteristics of the location and presence of tension between climate resilience and retail functionality enable conclusions and thus generalisations to be made as the study area is representative of the broader phenomenon of vulnerable shopping streets in compact, Dutch city centres (van den Brink et al., 2017). The study area is the city centre of Amersfoort, situated in the centre of the Netherlands. It fits into the aforementioned description of Dutch city centres.

In size, it is in the middle of the ten cities included in the preliminary analysis. Moreover, the four distinguished shopping streets are frequently present in its city centre. The city centre is characterised by a medieval, compact urban plan. An overview of the study site can be seen in Figure 12.

In terms of urban climate, the city centre of Amersfoort is subject to 'extreme' heat stress on a hot summer day (Vallei en Veluwe overheden, 2020). Moreover, there are considerable risks with extreme rainfall (Vallei en Veluwe overheden, 2020). Therefore, the study area suffers from the climatic problems that are described in the introduction.

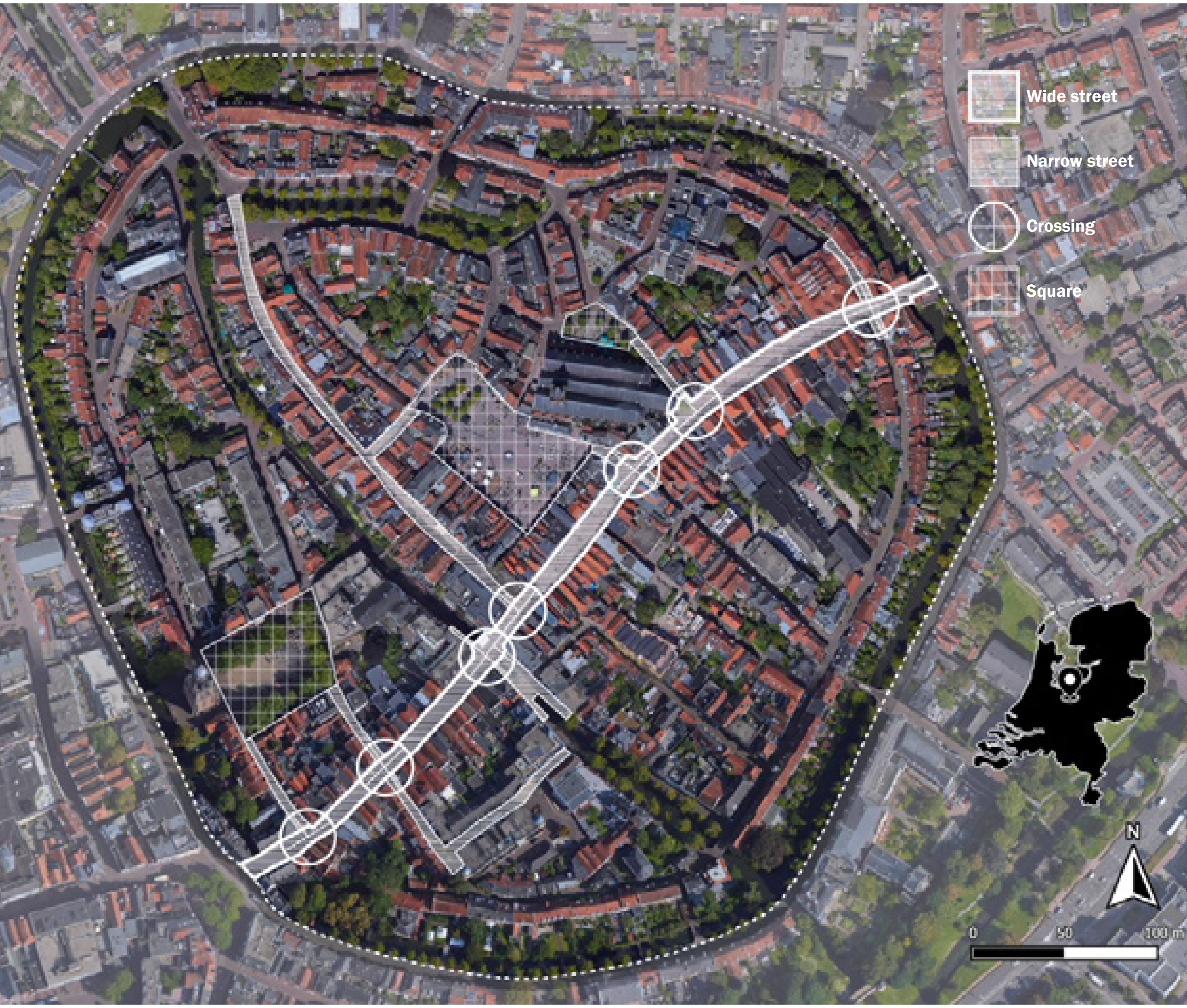


Figure 12: Study area of Amersfoort, with the four shopping street typologies.

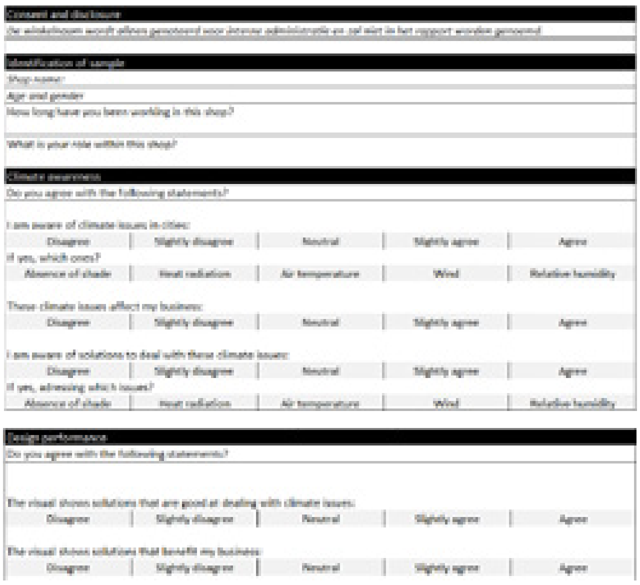
3.2. Setup of participatory design and interviews

In this thesis, an important stakeholder within the future users is shop owners in the city centre of Amersfoort. Therefore, the final design in this thesis must comply with their view of the functionality of the shopping streets. Shop owners form the target group of the participation process. In total, two participation sessions were held, with seven shop owners. Thus, on seven occasions in the first and second sessions, a shop owner was visited in their shop. Here, the conceptual ideas were shown and discussed. For the first participation session, conceptual visualisations were discussed. For the second participation session, conceptual site designs were discussed. As elaborated upon previously, this thesis discusses four shopping street typologies: the wide street, the narrow street, crossings between wide and narrow streets and crossings on squares. So, in both participation sessions, these four typologies were always the focal point of the discussion. Both the visualisations and site designs were made for the same locations in each of the four shopping street typologies. This way, the images were easy to understand and contextualise for the shop owners. Moreover, as participation session 1 developed knowledge that was applied in participation session 2, designs for both sessions could be compared due to the use of the same locations.

Each participation session was booked for 30 minutes. Depending on the availability of additional time, some sessions diverged from this planning. The participation sessions were informal. Explanations were provided for the shop owners regarding choices and impacts, but their input was stimulated whenever possible. Finally, the sample of the participation sessions needs to be elaborated upon. Three shop owners were located in the narrow street, two shop owners were located in the wide street and two shop owners were located on a crossing. No agreements could be made with shop owners on the square typology to participate. The average work experience of shop owners in their shop was 13,29 years. The work experience covered a range from 4 up to 34 years. In total, 4 shop owners were male and 3 shop owners were female. The shop owners covered quite an even spread across the age ranges from 25-34 up to 65+. Possible limitations of the sample are further elaborated upon in the discussion chapter.

3.2.1. Participation session 1

For the first participation session, statements were posed to get an understanding of the experience of the shop owners and their awareness of climate issues, as seen in Figure 13.


Consent and disclosure

De winkelnaam wordt alleen genoteerd voor interne administratie en zal niet in het rapport worden genoemd

Identification of sample

Shop name:

Age and gender

How long have you been working in this shop?

What is your role within this shop?

Climate awareness

Do you agree with the following statements?

I am aware of climate issues in cities:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

If yes, which ones?

Absence of shade	Heat radiation	Air temperature	Wind	Relative humidity

These climate issues affect my business:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

I am aware of solutions to deal with these climate issues:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

If yes, adressing which issues?

Absence of shade	Heat radiation	Air temperature	Wind	Relative humidity

Design performance

Do you agree with the following statements?

The visual shows solutions that are good at dealing with climate issues:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

The visual shows solutions that benefit my business:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

Figure 13: The posed statements in participation session 1

Moreover, for each shopping street typology, images were shown of the current situation and the climate-related problems, as well as images with the proposed interventions. Figure 11 shows this sequence. Finally, the proposed interventions were appraised through post-its. This resulted in an overview of all the interventions as established through SRQ1, with a score that represents its synergy with shopping street functionality. This overview can be found in Figure 22, further down in chapter 5.

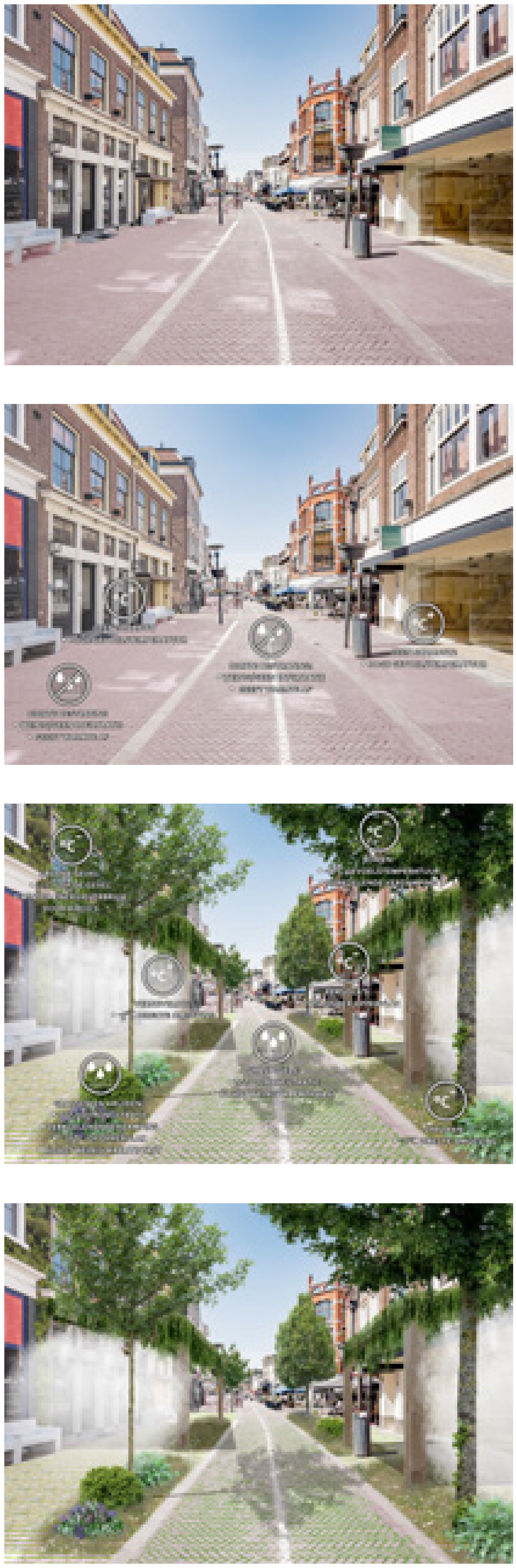


Figure 14: The before image (adapted from Funda (n.d.)), the before image with analysis, the after image with analysis and the after image of the conceptual impressions were shown for each shopping street typology.

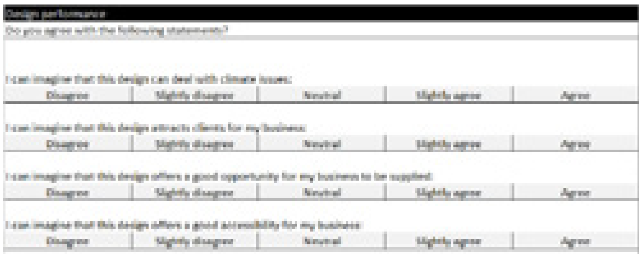
3.2.2. Participation session 2

For the second participation session, the interview was started with a three-part introduction to raise awareness of climate issues in cities, as well as recalling the memory of extreme heat during the summer of 2019, as previous summers have not been too hot. The interview questions were limited to several statements, to check how well the proposed site designs fit the requirements of shop owners. The statements can be found in Figure 15, and an overview of the four-part introduction can be found in Figure 16.

For each typology, a site design was developed, building on the research outcomes from the first participation session. Moreover, each site design was accompanied by a version with driving lines of emergency vehicles. This was done to show that the site designs were developed with these driving lines; fire truck width and turning radius, in mind. Sometimes, a visualisation or another site design version was required for additional explanation.

The initial setup of the participation sessions, based on the perspectives presented in the Theoretical Framework chapter, was discussed with Ivana Vujic, an expert in participation sessions revolving around climate challenges in cities and a researcher at Wageningen University & Research. Important takeaways were to make an inventory of the time shop owners worked in their shop and if they see an effect of weather on customer behaviour and to raise awareness of climate issues. The discussion validated the acknowledgement of the participation capacity of shop owners, taking the extrinsic and intrinsic factors into account, in line with the participation capacity network as proposed by Wojewska, Singh and Hansen (2021). After this initial section of the participation session, visualisations were shown. The various design proposals, presented through visualisations and site designs, as well as the microclimatic evaluations, were validated by Joao Cortesao, an expert in climate-responsive design and urban climate resilience from Wageningen University & Research. The results from the first participation session were discussed with Maikel Gijzen, the city centre retail manager of Amersfoort. This meeting was set up to see if the results were in line with his vision of current affairs within the city centre of Amersfoort. The overall conclusion established that the first iteration of the design criteria fits in with the philosophy for the city centre of making it more of a place to stay, rather than only a place to go. By including several experts to discuss and validate parts of the research, as well as following the concepts that are addressed within the theoretical framework, this thesis has aimed to contribute valid knowledge within the academic realm.

In the following chapters, the research questions are answered and addressed. Chapter 4 will address SRQ1 and the climate resilience interventions. The first part of Chapter 5 will address SRQ2, with the participation sessions including the interviews, visual impressions and first site designs. The second part of Chapter 5 will address SRQ3, with the design criteria derived from the participation sessions. Chapter 6 will address the site design that is produced, including the analysis of shop typologies and street typologies.


Design performance

Do you agree with the following statements?

I can imagine that this design can deal with climate issues:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

I can imagine that this design attracts clients for my business:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

I can imagine that this design offers a good opportunity for my business to be supplied:

Disagree	Slightly disagree	Neutral	Slightly agree	Agree

I can imagine that this design offers a good accessibility for my business:

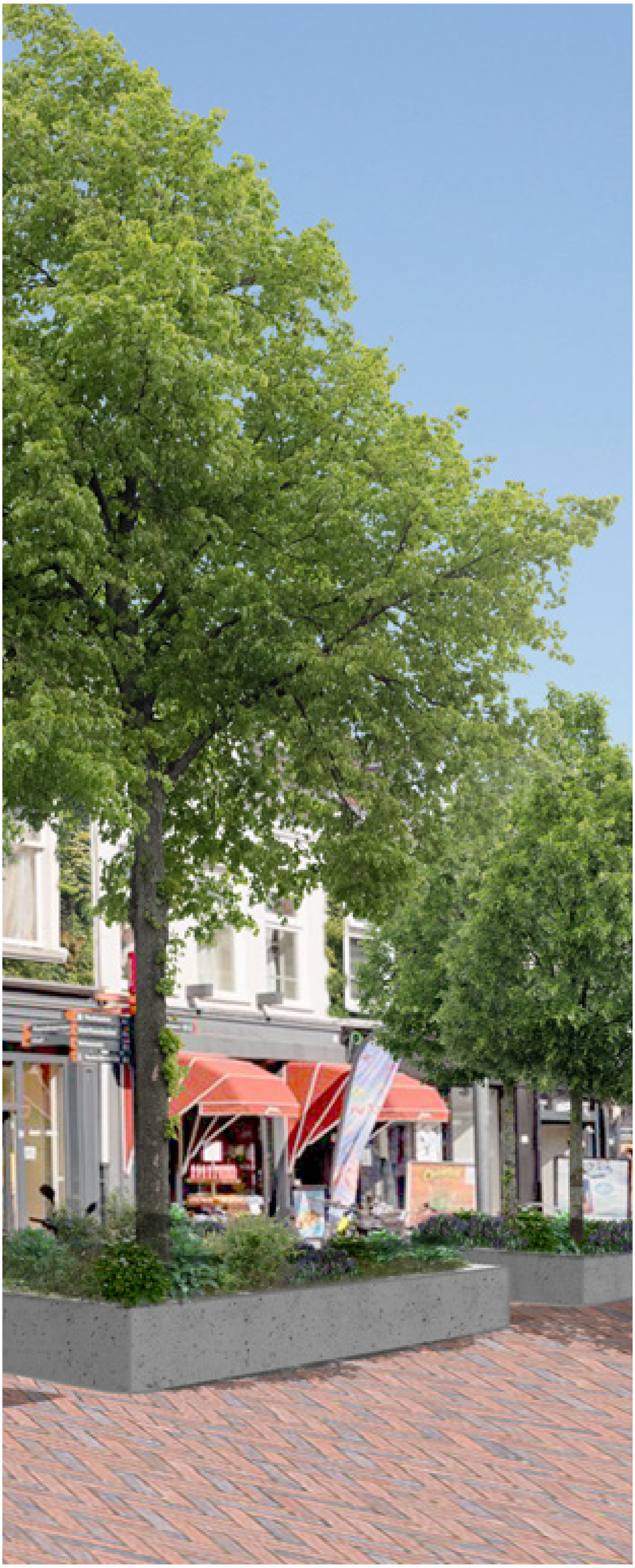
Disagree	Slightly disagree	Neutral	Slightly agree	Agree

Figure 15: The posed statements in participation session 2

Figure 16: The interview questions and the three-part introduction part of the second participation session. First image adapted from AT5 (2016).

4

4. RESULTS – RESEARCH FOR DESIGN



4.1. Possible interventions for climate-resilient shopping streets

Through a literature review, an inventory of 18 interventions to benefit climate resilience in shopping streets was established.

Databases such as Google Scholar, Scopus and the WUR library, as well as books on climate-resilient design, were used to perform the literature review. Some of the search terms and researched domains include climate-resilient design, urban climate, resilience, adaptation, green-blue grids, cooling effect of specific interventions, rainwater infiltration, shading and evapotranspiration.

Each intervention has different benefits concerning heat stress mitigation and dealing with extreme rain events.

Moreover, each intervention has a different applicability within shopping streets. For this chapter, the focus will be on climate-resilient performance. Chapter 5 will focus on the relation between the climate resilience interventions and the functionality of shopping streets.

Overall, a combination of shade, ventilation and evapotranspiration contribute to the reduction of heat stress. Moreover, permeable surfaces and greenery increase the rainwater infiltration capacity and temporary excess rainwater storage. Sometimes, combinations of interventions enhance the collective heat stress reduction or rainwater infiltration capacity. The literature study shows that in general, larger volumes of greenery are most beneficial for improving climate resilience.

The ambition for climate-resilient urban areas should be focused on increasing permeable surfaces, providing sufficient shade, enabling ventilation and increasing evapotranspiration. However, it has to be noted that this is only beneficial for situations with heat in the summer. The situation can be different in cooler seasons, where solar radiation and the blocking of wind flow can actually be desired (Lenzholzer, 2015). This discrepancy is further elaborated upon in the discussion chapter.

In the following sub-sections, each of the climate-resilient interventions is defined and described.

4.1.1. Green rooftops

There are different types of green rooftops. Extensive rooftops are relatively often applicable to the standard load-bearing capacity of existing roofs. These rooftops can be up to 7 cm thick. Intensive green rooftops can have a much larger thickness, but this often requires a reinforced roof structure. However, the cooling effect and water storage capacity of an intensive green rooftop can be much higher than that of an extensive rooftop. The thickness of the substrate layer determines the type of vegetation that can be implemented, which in turn influences the cooling effect and water storage capacity of a green rooftop (Pötz, 2016). On average, an extensive, green rooftop can hold around 35 litres of water per m2 (Floradak, 2016). In comparison, some intensive rooftops can hold between 110 and 160 litres of water per m2 (Pötz, 2016). Green roofs mainly cool the direct surroundings: their cooling effect can reach pedestrians when present up to 10 m of distance between the green roof and pedestrians (Liu et al., 2021). The surface temperature of a green rooftop can be up to 40 °C lower than that of a bitumen rooftop (Pötz, 2016).

4.1.2. Green balconies

The cooling effect and rainwater storage capacity of green balconies is dependent on the size of the plants, which is in turn dependent on the available space on the balcony. Generally speaking, the possibilities are limited. To get an indication of the effectiveness of climate-resilient interventions on balconies, the sections on ‘trees’ (applicable for small trees), ‘shading devices’, ‘shrubs’ and ‘grass and herbs’ can be read.

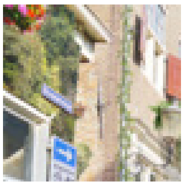
4.1.3. Trees

Trees provide cooling through shade and evapotranspiration (Lenzholzer, 2015) Coutts et al. (2015) reported in a study that:

“Trees were very effective at lowering thermal stress from very strong (UTCI>38 °C) down to strong (UTCI>32 °C). The influence of street trees on canyon air temperature and HTC was highly localized and variable, depending on tree cover, geometry, and prevailing meteorological conditions. The cooling benefit of street tree canopies increases as street canyon geometry shallows and broadens” (Coutts et al., 2015, p.55).

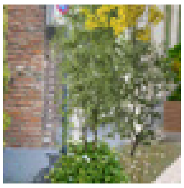
Moreover, tree crowns intercept rain and reduce the amount of water reaching the pervious or impervious surfaces below. Water stored on tree surfaces above the minimum water storage will drop off or flow down tree surfaces to the ground. Thus, maximum surface water storage acts as temporary excess storage. (Xiao and McPherson, 2016). Overall, the effectiveness of trees as a climate-resilient intervention is dependent on the species, age and size correspondently. As this thesis focuses on an urban context, it is important to note that the rooting system of trees can interfere with the availability of underground space, which is usually scarce in urban areas.

4.1.4. Green facades



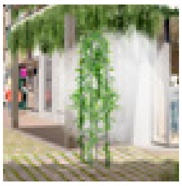
Green facades are facades where climbing plants (partly) cover the façade. There are several types of green facades, with self-climbing plants rooted in the ground surface, climbing plants rooted in the ground surface with an additional construction, hanging plants from pots on a balcony or rooftop and plants rooted in pots or a substrate attached to the façade itself (Pötz, 2016). Green facades are most effective in decreasing MRT with a height of <6m from ground level and at a distance of <2,5m. The largest cooling effect is achieved in an E-W orientation (as opposed to N-S) (Liu et al., 2021). Green facades can lead to a temperature decrease of up to 30 °C on the wall it covers, which can reduce energy consumption for indoor cooling by up to 40 per cent (Lenzholzer, 2015). In terms of potential implementation, there is an important note. The current state of the façade that greenery is applied to, needs to be inspected for faults, as plant roots can increase already present damage.

4.1.5. Facade gardens



A façade garden is defined as a vertical garden directly in front of a façade, rooted in a small, unpaved strip of open soil. The vegetation can be a combination of trees, shrubs and grasses and herbs, that form a non-uniform cover in front of the facade (Ren et al., 2022). The vegetation is not necessarily connected with the façade, unlike green facades, although façade gardens can be combined with a green façade behind them. Davis et al. (2019) conducted research that showed that façade gardens can cool air in the cavity between the façade garden and the façade behind it by an average of 6.2 °C. Additionally, the evapotranspiration of plants lowers the air temperature in front of the façade garden (Lenzholzer, 2015).

4.1.6. Climbing plant structures



For spaces where there is too little rooting space for a tree, climbing plants structures can be implemented. These structures most likely provide less shade than a tree, although this is dependent on the size and form of the structure. Climbing plants structures provide little benefit in terms of dealing with extreme rain events but can lower the air temperature through evapotranspiration (Lenzholzer, 2015).

4.1.7. Climbing plants cover

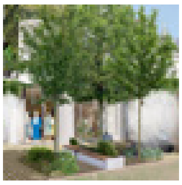
By guiding climbing plants above a street canyon, a climbing plant cover can be formed to cast shade onto the street. Depending on the foliage density, a large amount of solar radiation can be prevented from reaching the ground surface (Lenzholzer, 2015). Additionally, the climbing plant cover can temporarily hold a little bit of rainwater on its surface during an extreme rain event, providing more time for the street underneath to take up the rainwater without flooding the paved surfaces.

4.1.8. Shading devices

Temporary shades can be relocated based on occupational, daily and seasonal requirements. They can prevent up to 98% of solar radiation from directing onto people and urban surfaces and enhance outdoor thermal comfort through decreased radiant temperature (Osmond and Sharifi, 2017). Shading devices can be moveable, for example with a freestanding sunshade, or have a fixed location, such as a shadow curtain. Shadow curtains are directly mounted in between two buildings, covering the street underneath. These curtains can be flexible: being able to open and close the curtain according to the weather conditions (Lenzholzer, 2015). Moreover, the curtains can be removed at night, enabling the release of heat from buildings and other surfaces, improving night-time cooling of the city centre (Kluck et al., 2020).

4.1.9. Pocket park with seating

4.1.10. Pocket park with shrubs



As mentioned previously, trees can reduce the PET by around 6 °C underneath the canopy. Clustering trees into a pocket park can increase this PET reduction, due to a larger combined canopy and more evapotranspiration (Rahman et al., 2020). This effect can be further enhanced by the combination of tree clusters with a layer underneath the tree canopy of shrubs, grasses and herbs, as the evapotranspiration of shaded vegetation under trees can be higher than that of unshaded vegetation (Tan et al., 2021). The shaded area underneath the tree canopy can become a place for people to meet and sit down, therefore being a beneficial location to implement seating.

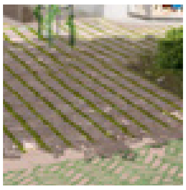
4.1.11. Shrubs

Shrubs can partially absorb the heat that is retained on the ground surface, as well as cool down wind flow that passes through the vegetation (Taib and Abdullah, 2016). Although the effect is lower than with trees, the evapotranspiration of shrubs contributes to a lower air temperature (Lenzholzer, 2015). Consequently, shrubs are reported to play a significant role in mitigating urban heat islands (Qiu et al., 2021).

4.1.12. Grass and herbs

The evapotranspiration of grasses and herbs contributes to a lower air temperature (Lenzholzer, 2015). However, this effect is limited in unshaded circumstances. When grasses and herbs are shaded, the cooling effect is increased (Armson, Stringer and Ennos, 2012; Tan et al., 2021). Replacing pavement with grass and herbs can lower surface temperature by up to 24°C (Armson, Stringer and Ennos, 2012). However, proper irrigation for grasses and herbs is vital. When the irrigation is not optimal, surface temperature reduction by grasses and herbs can decrease by 10°C (Osmond and Sharifi, 2017). Lastly, open soil with grass and herbs enables up to 100% rainwater infiltration, unlike with conventional pavement (Pötz, 2016).

4.1.13. Semi-permeable paving

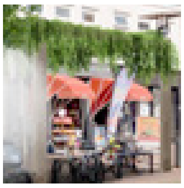


Evaporative cooling from permeable surfaces may decrease the surface temperature by up to 20˚C. Moreover, permeable paving allows water to drain and evaporate through the urban surfaces (Osmond and Sharifi, 2017). Lastly, permeable paving reduces surface runoff, increasing the capability of an area to deal with extreme rainfall (USGS, 2019). One application of semi-permeable paving is a combination of clinkers and open, spaces in between. The percentage of openings varies from around 15% to 40% and together with a permeable (soil) layer underneath the pavement, semi-permeable paving can allow up to 100% of rainwater infiltration. Another semi-permeable paving application is gravel. The light colour of gravel, thus having high reflective properties, in combination with its permeability, helps keep its surface temperature low (Pötz, 2016). Semi-permeable paving is applicable for purposes such as a footpath or parts of a square, but is not suited for purposes such as roads, as the load-bearing capacity of semi-permeable paving is limited (Geiger, Dreiseitl and Stemplewski, 2009).

4.1.14. Permeable surfaces

Permeable surfaces can be for example a grass lawn or bare soil. Grass lawns can contribute to a lower air temperature through evapotranspiration. However, when grass lawns are dried out, the cooling effect is diminished, and grass lawns can even contribute to a warmer microclimate. Thus, shading of grass lawns is recommended (Lenzholzer, 2015). Bare soils during extreme heat can too suffer from dryness, which results in a decrease in evapotranspiration and an increase in soil temperature up to 5 °C (Lemonsu et al., 2012). Again, this can be mitigated by providing shade.

4.1.15. Green pergolas



Green pergolas (partly) prevent solar radiation from warming up the surface underneath. Additionally, the climbing plants on the pergola structure provide extra cooling through evapotranspiration (Lenzholzer, 2015). As a result of the casted shade and evapotranspiration, green pergolas can cool the local air temperature by up to 5 °C at the pedestrian level (Chàfer et al., 2020).

4.1.16. Green planters

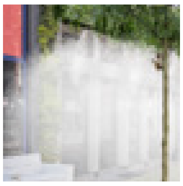
The cooling effect and rainwater storage capacity of planters is dependent on the size of the plants, which is in turn dependent on the available space within the planter. Planters contain their own layer of soil on top of the ground surface, meaning that there is more rooting space for plants when the underground space is limited. Planters can be fixed, but smaller planters can be moveable. This offers flexibility in the usage of public spaces. The disadvantage of a moveable planter, as opposed to a fixed planter, is the absence of direct contact with the soil layer underneath. Therefore, only plants with a relatively small rooting system can be used. However, the evapotranspiration of small plants still contributes to a lower air temperature (Lenzholzer, 2015). To get an indication of the effectiveness of climate-resilient interventions in planters, the sections on 'trees', 'shrubs' and 'grass and herbs' can be read.

4.1.17. Fountains

'Fountain' is a collective term for different variations of its concept. In this thesis, the focus is on an accessible square with several water sprays. Fountains can also entail a stagnant or slow-moving waterbody, where a base continuously holds water. When this is the case, the fountain can actually be warmer than its surroundings and is therefore not desirable, as stagnant water retains heat (Lenzholzer, 2015).

A fountain that sprays water upwards to around two metres high, can cause a temperature decrease of around 3 °C (Lenzholzer, 2015). The cooling effect can be increased in the right synergy with green components. The shading effect of greenery can decrease solar radiation reaching the surface of the fountain (Liu et al., 2021).

4.1.18. Water mist installations



Water mist provides local cooling which is negatively affected by wind speed (Liu et al., 2021). Moreover:

"*Misting fans affect distances up to 5m from the fan. Depending on the weather conditions, an air temperature reduction of 5-15˚C may occur in the immediate area around the misting fan. Misting fans are more effective when installed 2.4-3m above ground level*" (Osmond and Sharifi, 2017, p.28).

5

5. RESULTS – RESEARCH THROUGH DESIGN: PARTICIPATION

5.1. Synergies and trade-offs between retail and climate resilience

From chapter 4, we have derived which climate-resilient interventions can be applied in shopping streets. However, before we can implement these interventions, we need to know how they combine with retail functionality. Therefore, the climate-resilient interventions were implemented in conceptual visualisations and site designs.

All the data that was gathered in the participation sessions, can be found in the appendix. In the following sections, the preliminary analysis and results from the participation sessions are presented.

5.1.1. Participation session 1

As previously mentioned, the participation sessions revolved around four locations, in line with the four shopping street typologies as defined earlier. Figures 17 to 20 show each location.

Wide street

The wide street is characterised by a width of around 10 m. It is layouted with a central lane, open for vehicles.

Narrow street

The narrow street is characterised by a width of around 4,75 m. It is layouted with a central lane, open for vehicles, with two small sidewalks on either side.

Crossing

The crossing is characterised by a width of around 10 m for the wide street and 5,15 m for the perpendicular narrow street. Both streets are layouted with a central lane, open for vehicles.

Square

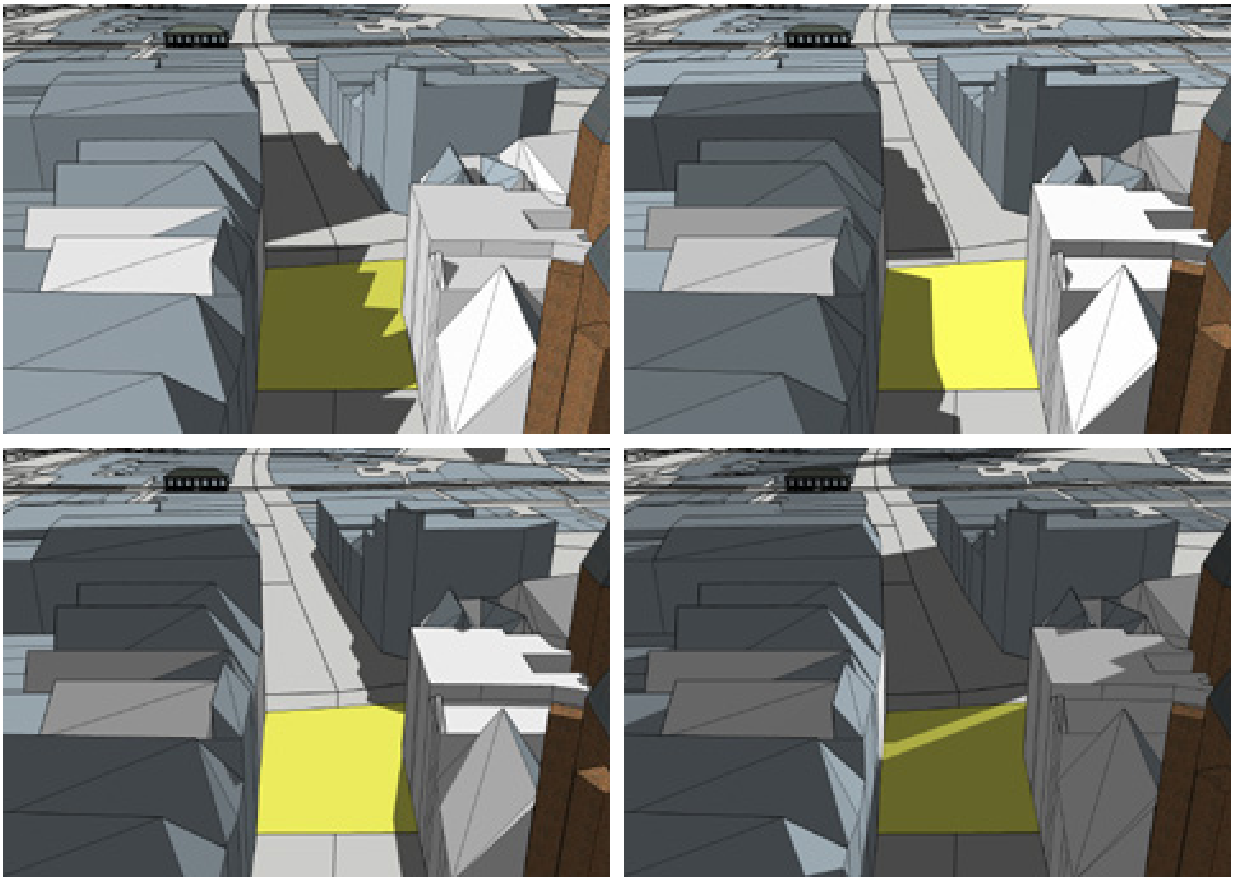
The square is characterised by a size of around 4300 m2. The square is layouted with several lines in a different pavement than the rest of the square. In the middle of the square, a fountain is located. Throughout the week and seasons, the square is either empty, filled with terraces or filled with market stands.

Figure 17: the wide street typology, adapted from Funda (n.d.)

Figure 18: the narrow street typology, adapted from Zairon (2015).

Figure 19: the crossing typology, adapted from (Funda, n.d.).

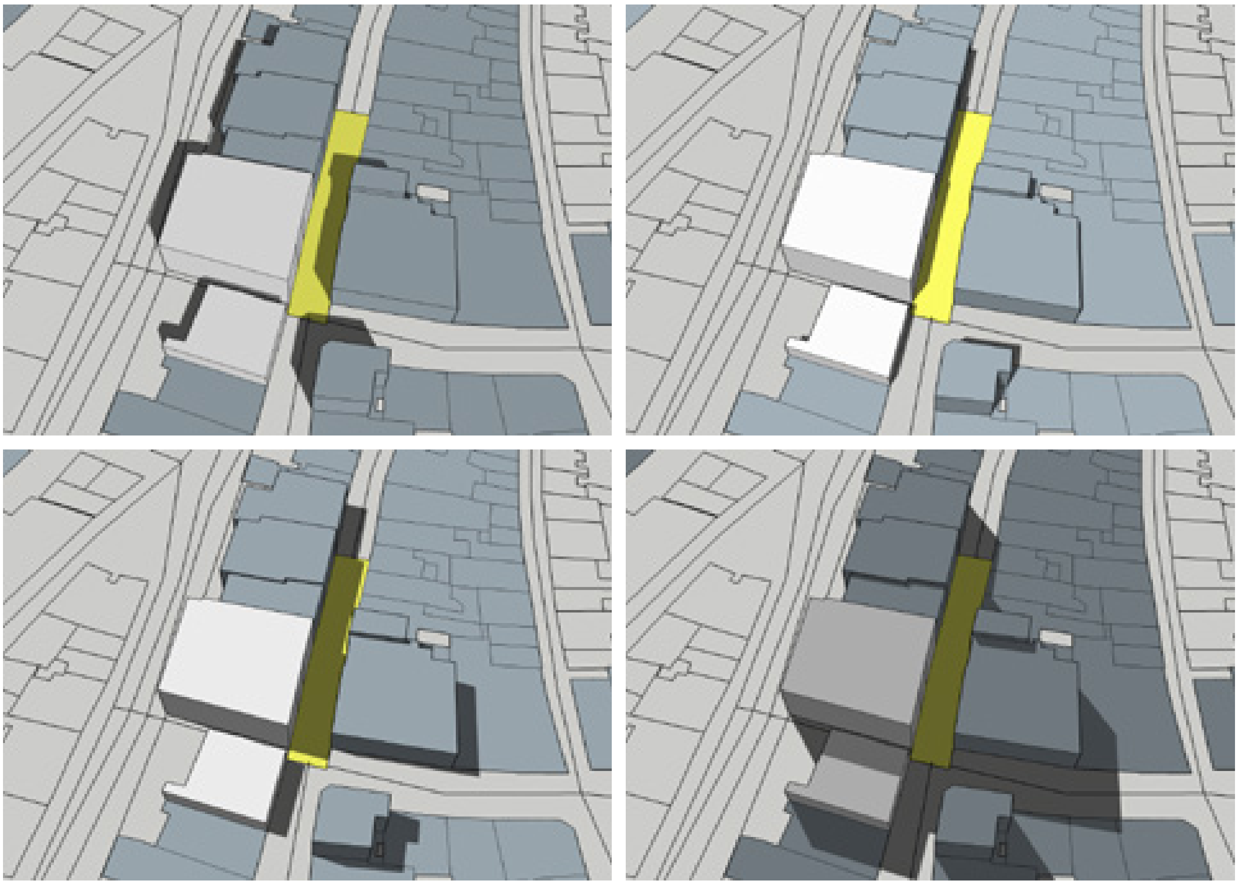
Figure 20: the square typology, adapted from Gemeente Amersfoort (2021).



From left to right: intervals of 09:00, 12:00, 15:00 and 18:00. As we can see, from 12:00 onwards, the wide street receives more and more solar radiation. At solar noon (13:41 on 1 July), the wide street is almost completely exposed to solar radiation.

Due to the large amount of exposure to solar radiation and largely paved surface, the wide street is not well adapted to extreme heat or extreme rainfall.

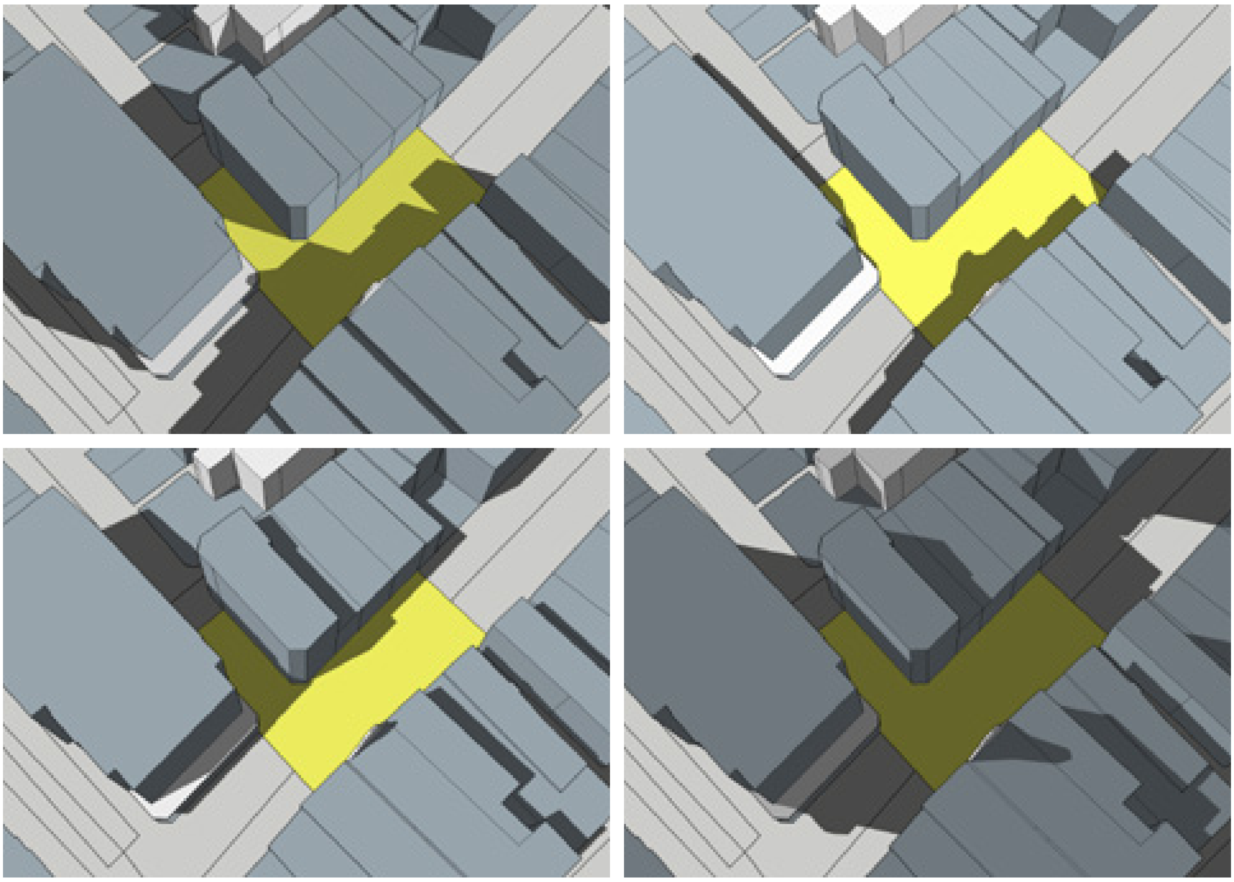
In the wide street, a combination of trees and pergolas provide shading, as well as evapotranspiration. Water mist installations, shrubs and grasses and herbs contribute to evapotranspiration. Grass tiles improve infiltration and retain less heat than traditional paving.



From left to right: intervals of 09:00, 12:00, 15:00 and 18:00. As we can see, around 12:00, the narrow street is almost completely exposed to solar radiation. In comparison to the wide street, the daily exposure is less, due to the smaller width of the narrow street.

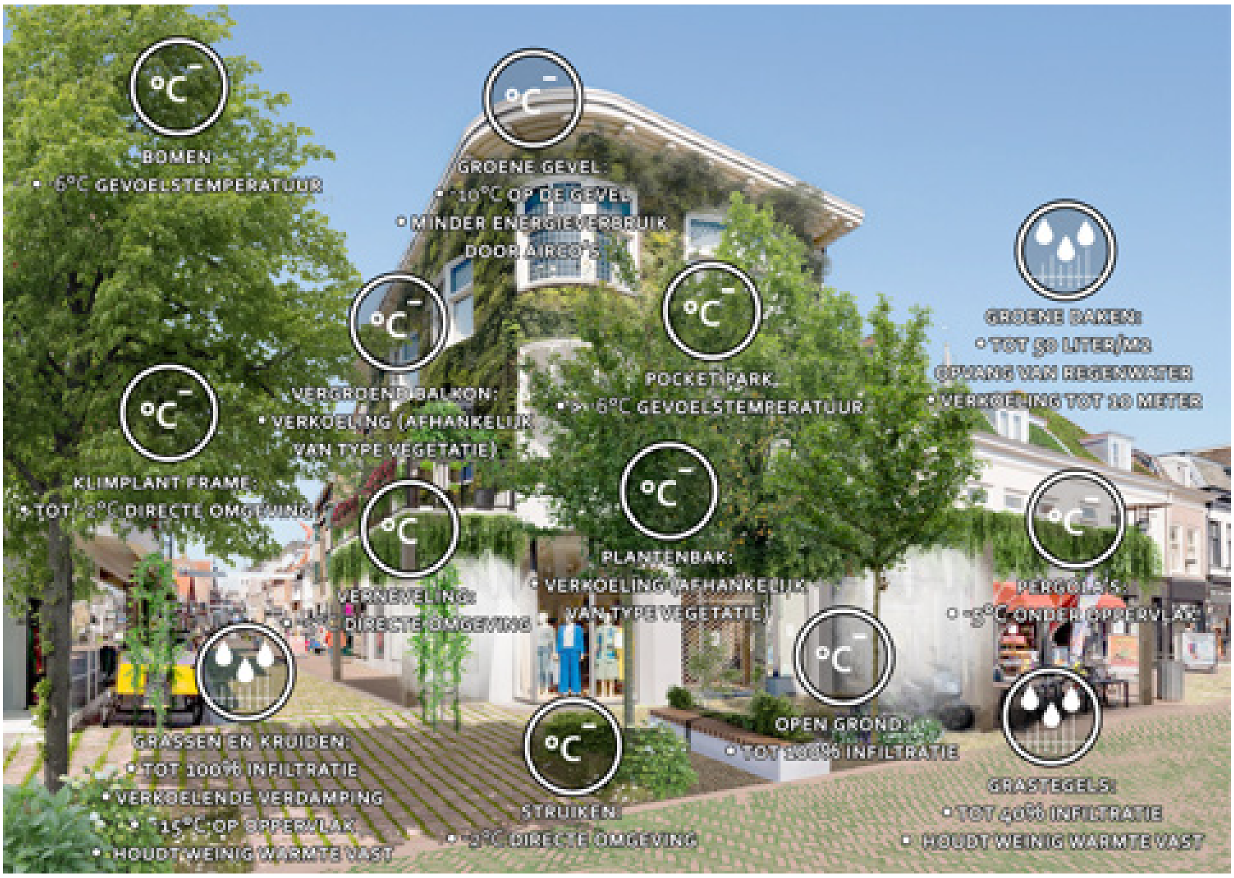
Whilst the period of exposure to solar radiation is limited, heat gets trapped in between the facades. Together with a largely paved surface, the narrow street is not well adapted to extreme heat or extreme rainfall.

In the narrow street, smaller and flexible interventions are used, in comparison to the wide street. Climbing plants covers and shading covers provide shade. The planters are moveable. Façade gardens are applied in front of building facades.

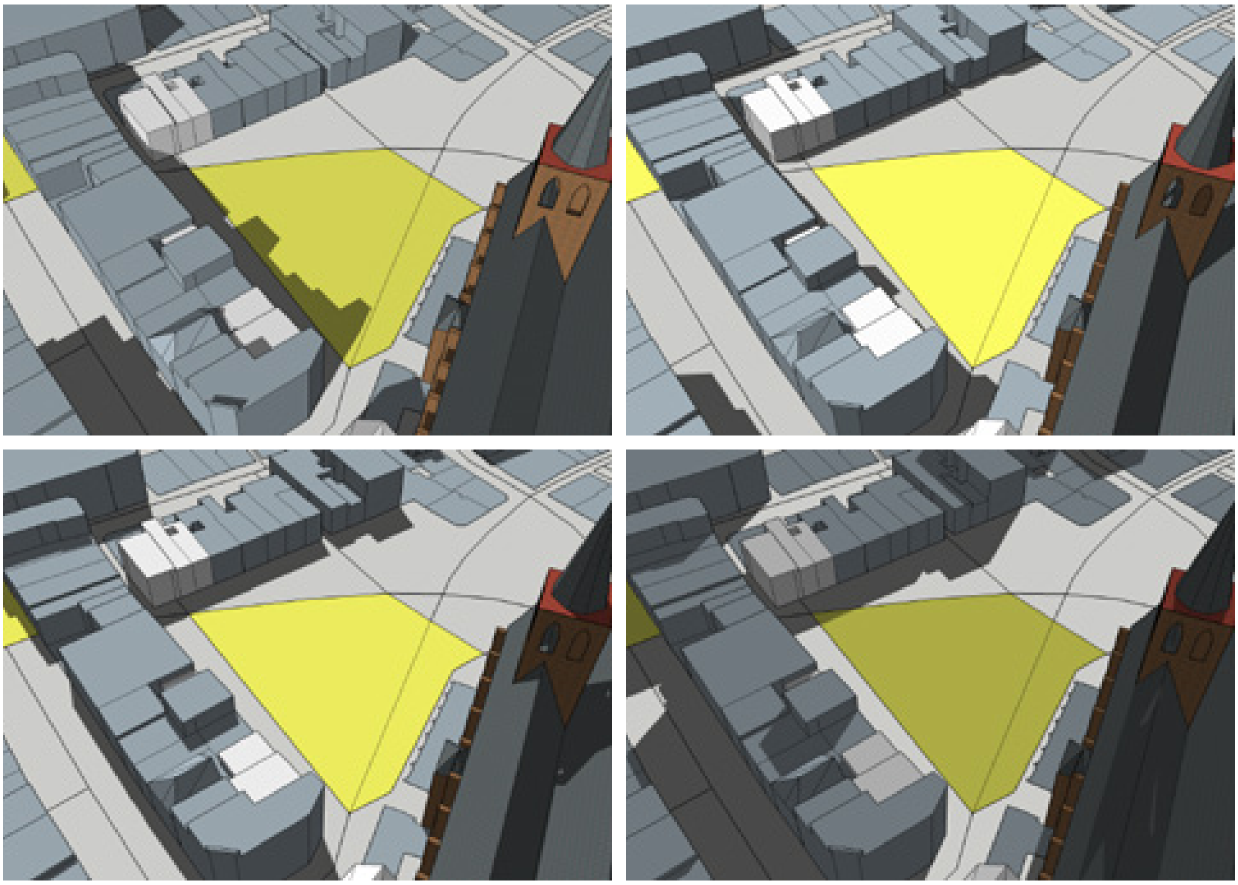


From left to right: intervals of 09:00, 12:00, 15:00 and 18:00. The exposure to solar radiation is similar to that of the wide street. At solar noon (13:41 on 1 July), the wide street is almost completely exposed.

Due to the large amount of exposure to solar radiation and largely paved surface, the wide street and narrow street on crossings are not well adapted to extreme heat or extreme rainfall.



For the crossing, some larger scale interventions are applied than in the wide street, due to more available space. Greenery is clustered into a pocket park, with integrated seating. Some larger trees are implemented.



From left to right: intervals of 09:00, 12:00, 15:00 and 18:00. Throughout large parts of the day, the square is almost completely exposed to solar radiation. As the square is predominantly open, solar radiation has free reign.

Due to the large amount of exposure to solar radiation and largely paved surface, the square is not well adapted to extreme heat or extreme rainfall.

On the square, the large amount of space was utilised to implement a pocket park with shrubs. An accessible fountain with water sprays provides cooling, whilst large areas of gravel offer lower surface temperatures without the loss of use for terraces or market stands.

Intervention appraisal through post-its

For each intervention, the shop owners could give a score through a red, yellow or green post-it. A red post-it represented serious critique, a yellow post-it represented potential but doubtful and a green post-it represented a good idea. Additionally, the shop owners could write down a short explanation why they gave a certain score. An example can be seen in Figure 21.

The appraisal system was experienced as convenient by the shop owners, as it helped structure the discussion and limit the time that was used up for the discussion of each intervention. Sometimes, shop owners took the initiative to go through the interventions one by one themselves, but in other instances, the post-its helped to steer attention to the next intervention. Moreover, the post-its made sure that each intervention was discussed. All appraised conceptual impressions with post-its can be found in the appendix.

Figure 21: An appraised impression with post-its

Scores for each intervention

Through the first participation session, each intervention received a total score. For each of the seven shop owners, the post-it colour corresponding to each intervention was added. However, sometimes shop owners wrote down an explanation that represented a different colour than the post-it they applied. For example, they could write down doubts, whilst applying a green post-it. Therefore, on a few occasions, the colour had to be corrected during the processing of the results. For transparency, both score totals, so with and without correction, are shown. The overview can be seen in Figure 22.

In the score column, the first colour in the order represents the dominant post-it colour that was given to that intervention. For example, when looking at the score (corrected colours) column of shrubs, three yellow scores, three red scores and one green score were given. In instances where two scores were tied, the most positive colour was put at the front. The reasoning behind this was to stimulate thinking in possibilities, rather than in impossibilities.

Intervention	Score (colours)	Overall takeaways	Score (corrected colours)
Trees	🟢🟢🟢🟢🟢🟡🟡	Trees are desired, difficult because of minimum height trucks and wide bed. Trees should be clustered	🟢🟢🟢🟢🟡🟡🟡
Shrubs	🟡🟡🟡🔴🔴🔴🟢	Beds of vegetation are nice for the overall image, not vandalism proof. Collects garbage.	🟡🟡🟡🔴🔴🔴🟢
Grass and herbs	🟡🟡🟡🔴🔴🔴🟢	Beds of vegetation are nice for the overall image, not vandalism proof. Make compartments of greenery. Collects garbage.	🟡🟡🟡🔴🔴🔴🟢
Semi-permeable paving	🟡🟡🟡🟡🟢🟢🟢	Desired for green image, strong enough for trucks? (expected transition w/hub). Currently foundation underneath the street. Wheelchair/heels/rain/frost accessible?	🟡🟡🟡🟡🟡🟢🟢
Green pergolas	🟡🟡🟡🟡🟢🟢🔴	Nice, if done in cooperation with shop owners. Think about minimum height emergency vehicles. Limits the view. Moisture that penetrates the facades (damage)? Does it interfere with people going in and out of shops?	🟡🟡🟡🟡🟡🟢🟢
Green facades	🟢🟢🟢🟢🟡🟡🟡	Looks nice, location is critical (preserve historical features). Moisture that penetrates the facades (damage)?	🟡🟡🟡🟡🟢🟢🟢
Watermist installations	🔴🔴🔴🔴🔴🟡🟡	Not desired	🔴🔴🔴🔴🔴🟡🟡
Green balconies	🟢🟢🟢🟢🟢🟢🟢	Nice for the overall image	🟢🟢🟢🟢🟢🟢🟢
Facade gardens	🟢🟢🟢🟢🟡🟡🔴	Good idea, easy to implement. Vandalism proof?	🟢🟢🟢🟢🟡🟡🔴
Planters	🟡🟡🟡🟡🟢🟢🟢	Good idea, make them moveable. Can attract bicycles to be parked against. Can be obstacles.	🟡🟡🟡🟡🟢🟢🟢
Climbing plants structures	🔴🔴🔴🟢🟢🟡🟡	Looks very nice, but not solid enough (vandalism)	🟡🟡🟡🔴🔴🔴🟢
Climbing plants cover	🟢🟢🟢🟢🔴🔴🟡	Looks nice and vandalism proof. Is dark however. Difficult to maintain. Prolongs rainwater dripping.	🟢🟢🟢🟢🔴🔴🟡
Green rooftops	🟢🟢🟢🟢🟡🟡🟡	Looks nice, does it interfere with protected monuments/image?	🟢🟢🟢🟢🟡🟡🟡
Shading devices	🔴🔴🔴🔴🔴🟢🟡	Makes noise in wind, does not look good. Gets dirty. Prolongs rainwater dripping	🔴🔴🔴🔴🔴🟢🟡
Fountains	🟢🟢🟢🟢🟢🟡🟡	Nice element, fun for kids. Perhaps nice in combination with rainwater retention.	🟢🟢🟢🟢🟡🟡🟡
Pocket park with seating (crossing)	🟢🟢🟢🟢🟢🟢🟡	Nice, robust in combination with seating element. Seating elements are very much desired. Difficult with accessibility trucks. Cluster of trees creates a lot of shade.	🟢🟢🟢🟢🟢🟢🟡
Pocket park with shrubs (square)	🟢🟢🟢🟢🟢🟡🔴	Nice, difficult in combination with market/emergency protocol. Clustered trees are desired.	🟢🟢🟢🟢🟡🟡🔴
Permeable paving	🟡🟡🟡🟡🟢🟢🔴	Gravel nice in terms of infiltration and image. Could it be green? Gravel fits the city image. Should function fine (look at Paris)	🟡🟡🟡🟡🟢🟢🔴

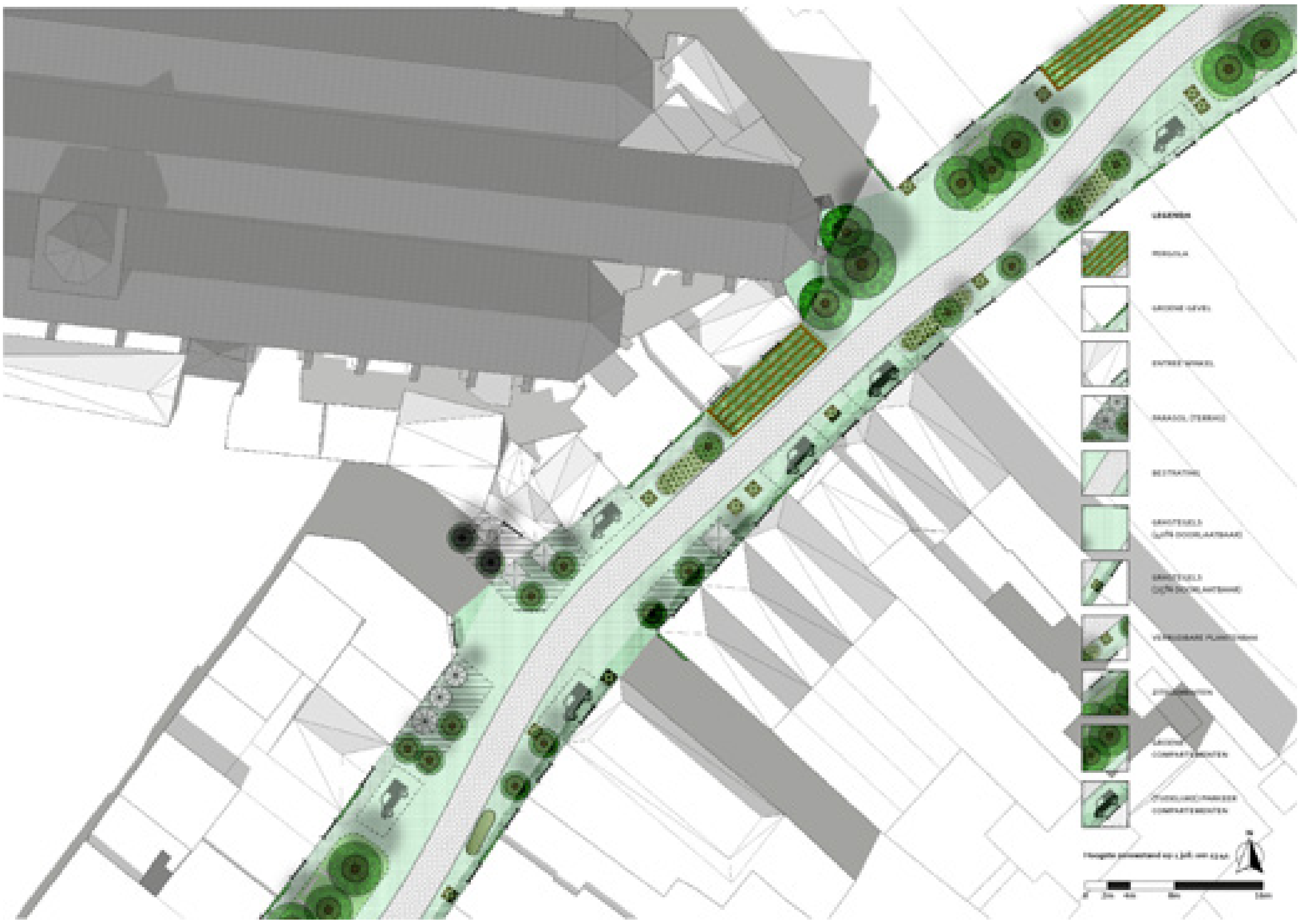
Figure 22: the scoring overview

5.1.2. Participation session 2

Wide street

The first image represents the effect of green facades and pergolas. The second image shows the proposed site design with driving lines for emergency vehicles. The third image shows the site design without the driving lines.

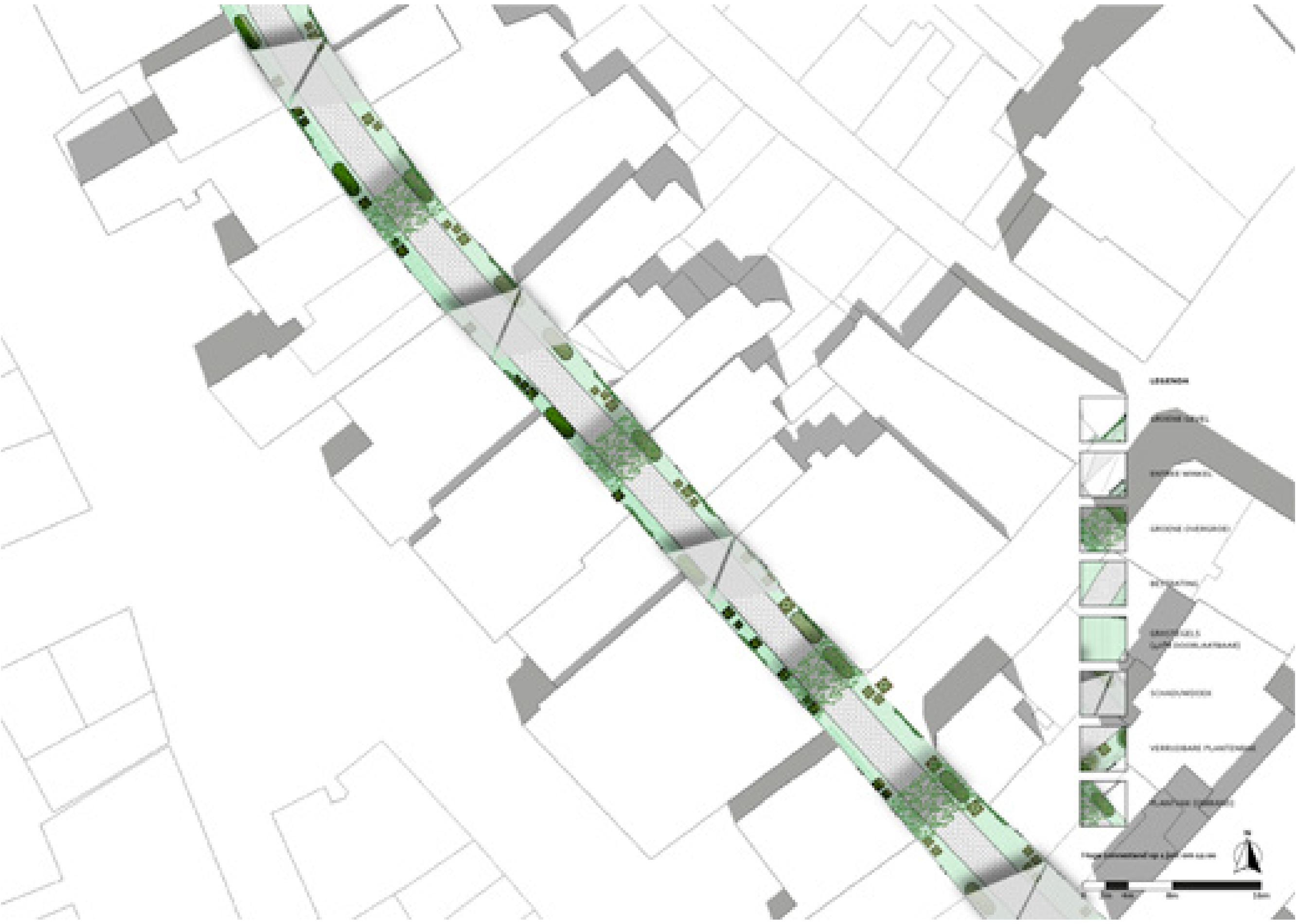
In the wide street, several (temporary) parking spaces are incorporated to improve possibilities for shop supply. Greenery is clustered to limit its interference with retail functionality. An open, 3,5m wide paved line provides a good accessibility.



Narrow street

The image shows the proposed site design for the narrow street typology.

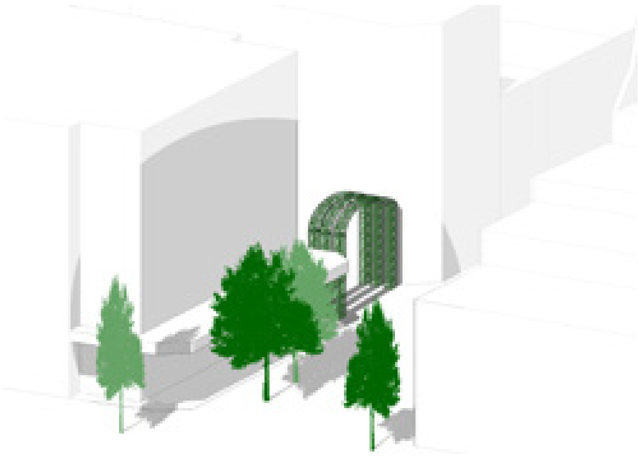
In the narrow street, shading devices and green, climbing plant covers are alternated to provide shade in the street, without covering the entire street. A central lane of pavement with sidewalks of green tiles takes up the street. Moveable planters are positioned on the sidewalks, to provide flexibility in space.

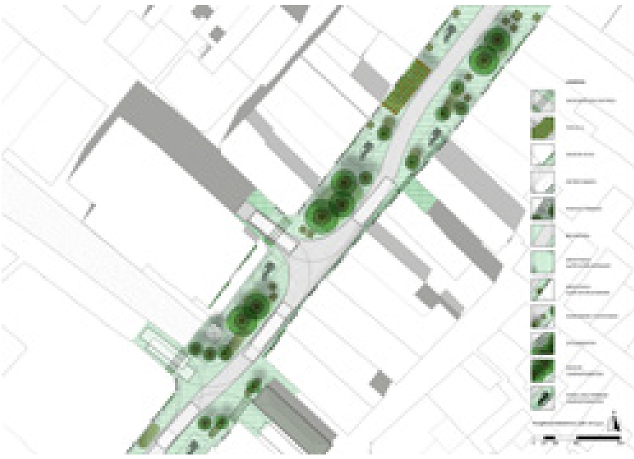


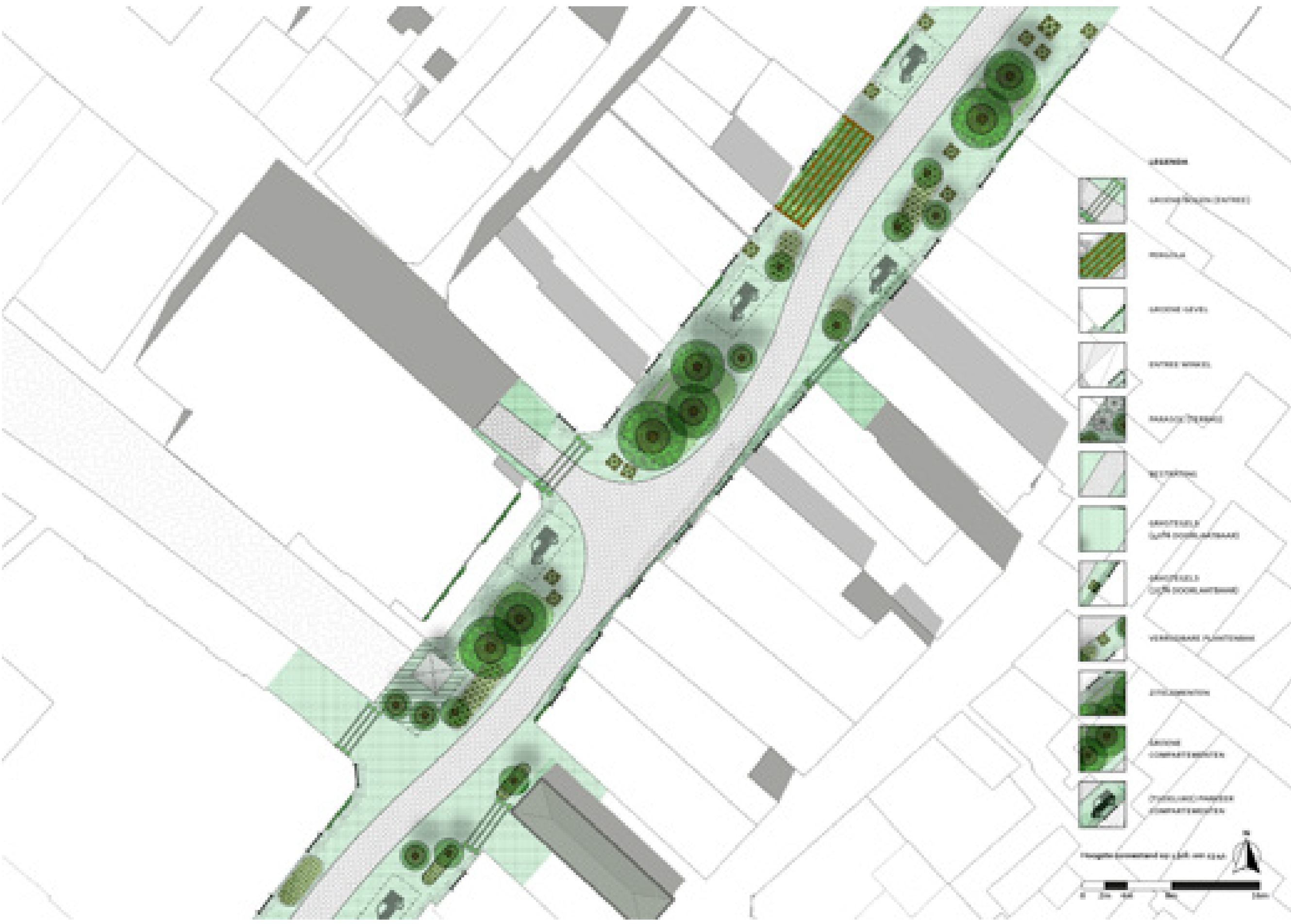
Crossing

The first image represents the effect of different tree sizes and a green arch for the entrance of side streets. The second image shows the proposed site design with driving lines for emergency vehicles. The third image shows the site design without the driving lines.

In the crossing, the difference in spatial perception of different tree crown size is stressed. By alternating tree crown sizes, the public space can be allocated in a more dynamic way.







Square

The first image shows the site design with driving lines for emergency vehicles. The second image shows the site design with terraces. The third image shows the site design with market stands in place.

The square is divided into compartments, with several open routes along the compartments. The compartments consist of gravel, with a central accessible fountain. Trees provide shade and in between, several open spaces are maintained for either market stands or terraces.

An overview of the synergies and trade-offs between climate resilience and retail functionality

Figure 23 shows scores for the combination between a climate resilience intervention and a building typology. This way, the spatial impact and allocation possibilities of a climate-resilient intervention can be considered. This is very important to be able to apply knowledge gained through the participation sessions in a final design. The overview was derived by analysing the data from the participation sessions. Some interventions, such as a green roof or shrubs, do not interfere or have very little interference with building typologies. However, a tree for example, can block the view of a shop display. Putting a tree directly in front of a shop window that is used for product display, is therefore not desired. It is however possible to plant a tree in between two shop facades, so the view of both shop displays is not obstructed. Therefore, one minus is given to the combination of trees with shops that use their shop window for product display. The combination has complications, but with careful consideration, the combination is not impossible. Throughout the participation sessions, it became apparent which combinations could work very well, and which combinations would not work well.

	SHOP WHICH USES SHOP WINDOW FOR PRODUCT DISPLAY	SHOP WHICH DOES NOT USE SHOP WINDOW FOR PRODUCT DISPLAY	SHOP WITH PLAIN (SECOND STORY) FACADE	SHOP WITH DETAILED (SECOND STORY) FACADE	HORECA WITH TERRACE IN FRONT OF BUILDING	HORECA WITHOUT TERRACE IN FRONT OF BUILDING	BUILDING SIDES OR EXTENSION
TREES	-	+	+	-	-	+	++
SHRUBS	+	++	++	++	+	++	++
GRASS AND HERBS	+	++	++	++	+	++	++
SEMI-PERMEABLE PAVING	+	++	++	++	+	++	++
GREEN PERGOLAS	-	+	+	-	-	+	++
GREEN FACADES	--	-	++	-	-	-	++
WATERMIST INSTALLATIONS	--	-			+	-	++
GREEN BALCONIES	++	++	++	+	++	++	++
FACADE GARDENS	--	-			--	-	++
PLANTERS	+	++			-	+	++
CLIMBING PLANT STRUCTURES	-	+			-	+	++
CLIMBING PLANTS COVER	++	++	++	+	--	+	++
GREEN ROOFTOPS	++	++	++	++	++	++	++
SHADING DEVICES	++	++	++	+	--	++	++
FOUNTAINS	--	--			--	--	+
POCKET PARK WITH SEATING	-	+			--	-	++
POCKET PARK WITH SHRUBS	-	+			--	-	++
PERMEABLE PAVEMENT	-	-			-	-	++

LEGEND:

(grey)	--	-	+	++
COMBINATION IS NOT APPLICABLE	COMBINATION IS NOT DEEMED FEASIBLE	COMBINATION HAS COMPLICATIONS BUT IS POSSIBLE IN SOME INSTANCES WITH CAREFUL CONSIDERATION	COMBINATION IS OFTEN FEASIBLE, WITH CONSIDERATIONS	COMBINATION IS DEEMED FEASIBLE, WITH VERY LITTLE COMPLICATIONS

Figure 23: synergies and trade-offs overview

5.2. Improving the acceptance of shop owners towards climate resilience

Through chapters 4 and 5.1, knowledge was gathered on which climate-resilient interventions can be applied in shopping streets and how they combine with retail functionality. In chapter 5.2, design criteria that should be adhered to when implementing climate-resilient interventions in shopping streets are addressed. Overall, chapter 5.2 deals with sub-research question 3: 'What is the current acceptance of shop owners towards climate-resilient interventions and how can this be improved?'

Participation session 1

I am aware of climate issues in cities: 3,57
Climate issues affect my business: 4,00
I am aware of solutions to deal with climate issues: 3,29

The visual shows solutions that are good at dealing with climate issues:	
4,86 – Wide street	4,86 – Narrow street
4,71 – Crossing	4,57 – Square

The visual shows solutions that benefit my business:	
4,29 – Wide street	4,71 – Narrow street
4,57 – Crossing	4,57 – Square

Participation session 2

I can imagine that this design can tackle climate issues:	
4,86 – Wide street	5,00 – Narrow street
4,86 – Crossing	5,00 – Square

I can imagine that this design attracts customers to my business:	
4,86 – Wide street	4,86 – Narrow street
5,00 – Crossing	5,00 – Square

I can imagine that this design enables a good supply of my business:	
3,43 – Wide street	3,00 – Narrow street
3,43 – Crossing	4,14 – Square

I can imagine that this design enables good accessibility of my business:	
3,86 – Wide street	3,86 – Narrow street
3,86 – Crossing	4,14 – Square

Figure 24: The scores given for each of the statements posed during participation sessions 1 and 2

5.2.1. The current acceptance of shop owners

Firstly, the first part of SRQ3 needs to be addressed. To improve the acceptance of shop owners towards climate-resilient interventions, we need to find out what the current acceptance is. This was done through posing statements during the participation sessions. Shop owners could agree or disagree with several statements. For each level of (dis)agreement, a score was assigned. As the level of agreement ranged from disagree, slightly disagree, neutral, slightly agree to agree, all scores range from 1 (disagree) to 5 (agree). Figure 24 shows the average scores for each of the statements.

The overview in Figure 24 gives some interesting insights. Generally, shop owners realise that climate issues affect their business, but they are not so aware of possible solutions. In the first participation session, shop owners were quite positive about the conceptual impressions overall. Their concerns were mainly about the possibility for their shop to be supplied and the accessibility for all users. These concerns are related to the lack of (temporary) parking spaces and the large percentage of grass tiles. Grass tiles can make traversability for a person in a wheelchair more difficult for example.

Therefore, in participation session 2, specific statements on shop supply and accessibility were posed. This way, more specific discussion on these topics was initiated and improvements on these topics within the conceptual site design could be tested. As can be seen in Figure 24, participation session 2 showed that shop owners are convinced about the effectiveness of interventions regarding the tackling of climate issues. Moreover, they stated that climate-resilient interventions in shopping streets can attract customers for their business. Both categories scored a minimum of 4,86 out of 5. However, the shop owners did retain concerns on shop supply possibilities and accessibility during participation session 2. In these categories, the scores ranged from 3,43 to 4,14, which is not bad, but shows that there is room for improvement.

Some of the issues regarding shop supply and accessibility were solved in the conceptual designs shown during participation 2, in comparison to the conceptual impressions shown in participation session 1. An open, 3,5m wide paved lane in all typologies was perceived as beneficial for the accessibility of the shopping street by shop owners. Moreover, (temporary) parking spaces for small electric delivery vans improved the possibility for shop supply. However, shop owners stressed the need for conventual paving connecting the open, 3,5m wide paved lane to each of the shops. Moreover, some (temporary) parking spaces needed to still fit a truck, to enable the infrequent temporary parking of a large supply truck for example.

Overall, the participation sessions showed that shop owners are acceptant and embrace the idea of climate-resilient interventions regarding tackling climate issues and attracting customers. Shop owners acknowledged that climate-resilient interventions do not necessarily prevent possibilities for shop supply and good accessibility of their business, but their main concerns did regard these topics. Therefore, to improve the acceptance of shop owners towards climate-resilient interventions, design criteria were formulated to be used in the final design of this thesis.

5.2.2. Design criteria for novel, climate-resilient shopping streets

Through participation sessions 1 and 2, an overview was derived with the design criteria that a design for climate-resilient shopping streets should adhere to.

From the criteria that were formulated after participation session 1, several design solutions were derived. These design solutions were tested in participation session 2, to test if the initial set of design criteria would be feasible to improve the acceptance of shop owners towards climate-resilient interventions. Through the two participation sessions, design criteria evolved, which finally led to the overview in Figure 25. The design criteria are categorised in shopping streets needing to be climate-resilient (green), attractive (yellow) and functional (orange).

In the conclusion chapter of this thesis, a complete overview of practice-orientated design guidelines for potential implementation is given, based on the results as presented in Chapters 4 and 5.

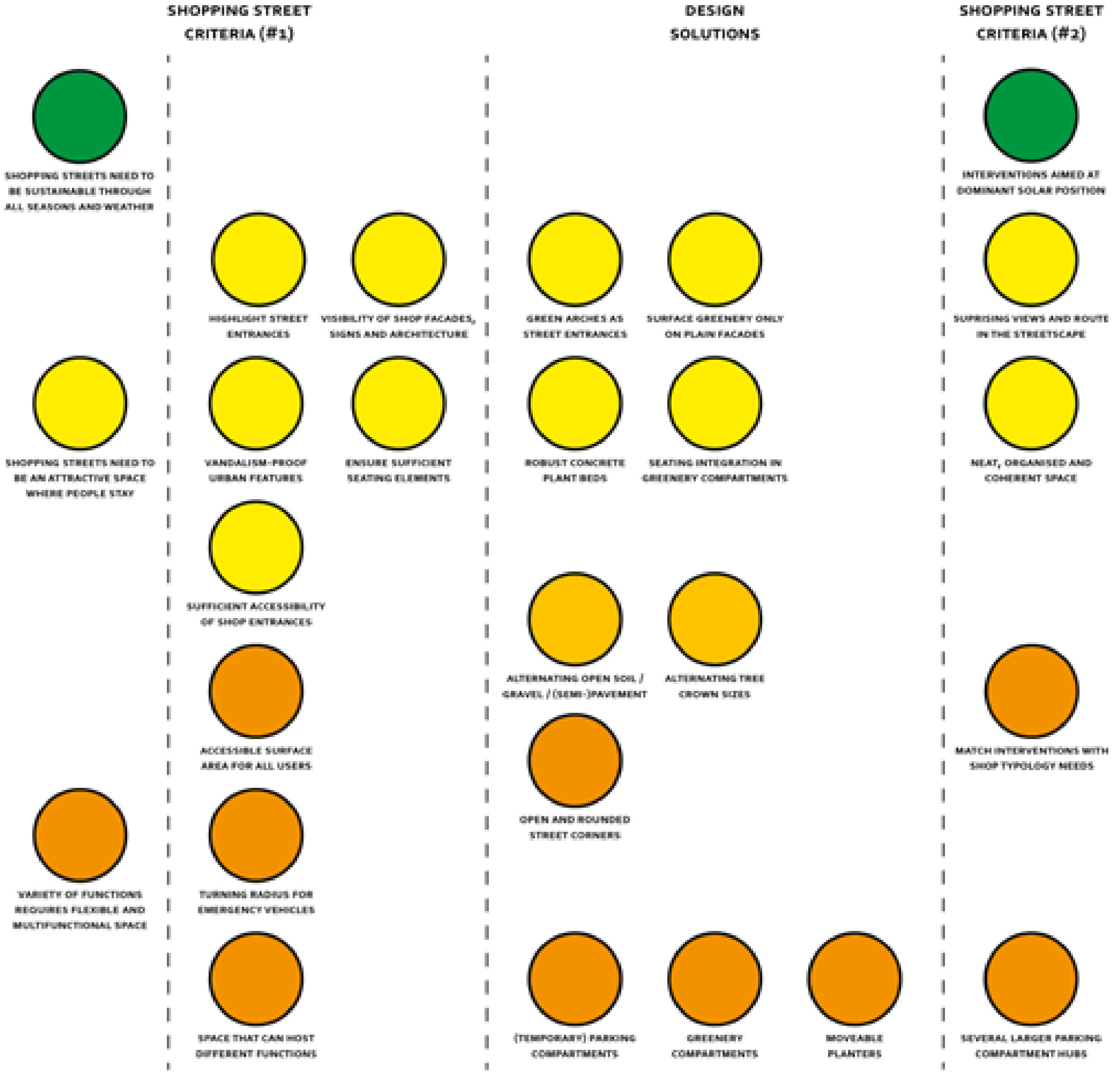


Figure 25: the design criteria

6

6. RESULTS – RESEARCH THROUGH DESIGN: DESIGN PRODUCTS AND MICROCLIMATIC EVALUATION

6.1. Site analysis

Before applying the results of chapters 4 and 5 to a final design for the study area, a site-specific analysis was needed.

Figure 26 shows the study area, which includes all shopping streets that are present within the city core of Amersfoort.

Through the theoretical framework, two main indicators for climate resilience were established: heat stress and rainwater infiltration capacity. Moreover, the KNMI climate scenario W(H) for 2050 is used.

Firstly, therefore, Figure 27 shows the heat stress in the study area in 2050. As can be seen, large parts of the study area suffer from extreme heat stress levels 1 or 2. The coolest areas within the study area, still fall within the strong heat stress category.

Figure 28 shows the depth of rainwater puddles that remain on the ground surface after a rain event of 74mm in 1 hour. This is a rain event that occurs once every 250 years and is regarded as a stress test event (Vallei en Veluwe overheden, 2020). Generally, rainwater depth ranges from 5-15 cm. Especially the narrow streets show a lot of hotspots with rainwater nuisance. Within the wide street and square, hotspots of rainwater nuisance are more spread out.

As established through the participation sessions, some interventions, such as green facades and green roofs, can interfere with protective guidelines for listed buildings. Therefore, Figure 29 shows the listed buildings within the study area. The map illustrates that large parts of the study area consist of listed buildings. In this thesis, only non-listed buildings are deemed applicable for climate-resilient interventions, to not interfere with protective guidelines.

Finally, Figure 30 shows the building typologies within the study area. This way, the conclusions from the combinations overview shown in chapter 5 can be applied to the study area.

Through the sequence of analysis maps, it becomes clear where climate-resilient interventions are needed the most and which locations are suitable for which climate-resilient interventions. By applying the knowledge gained from the participation sessions and the analysis, a masterplan has been created, as shown in chapter 6.2.

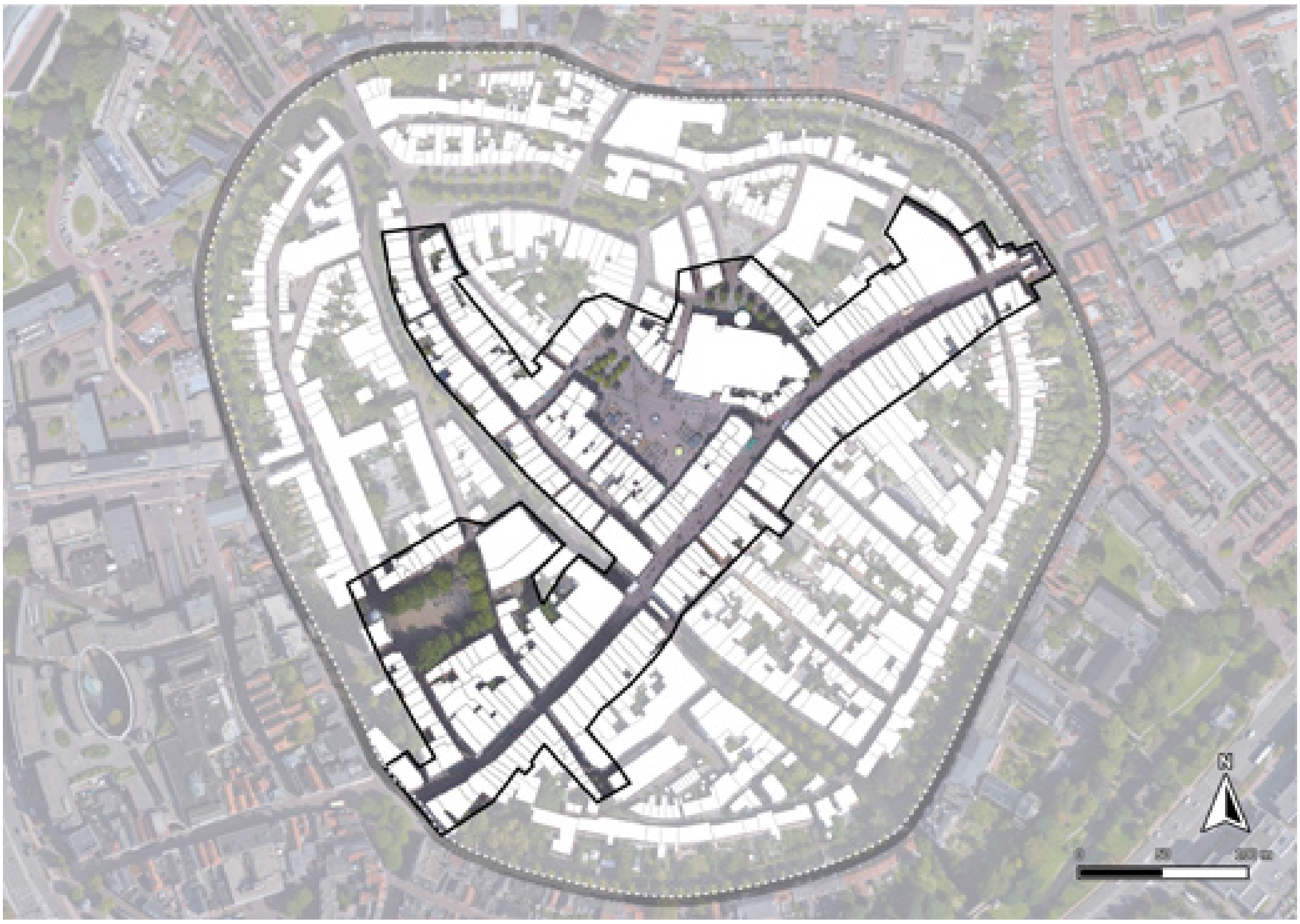


Figure 26: the study area

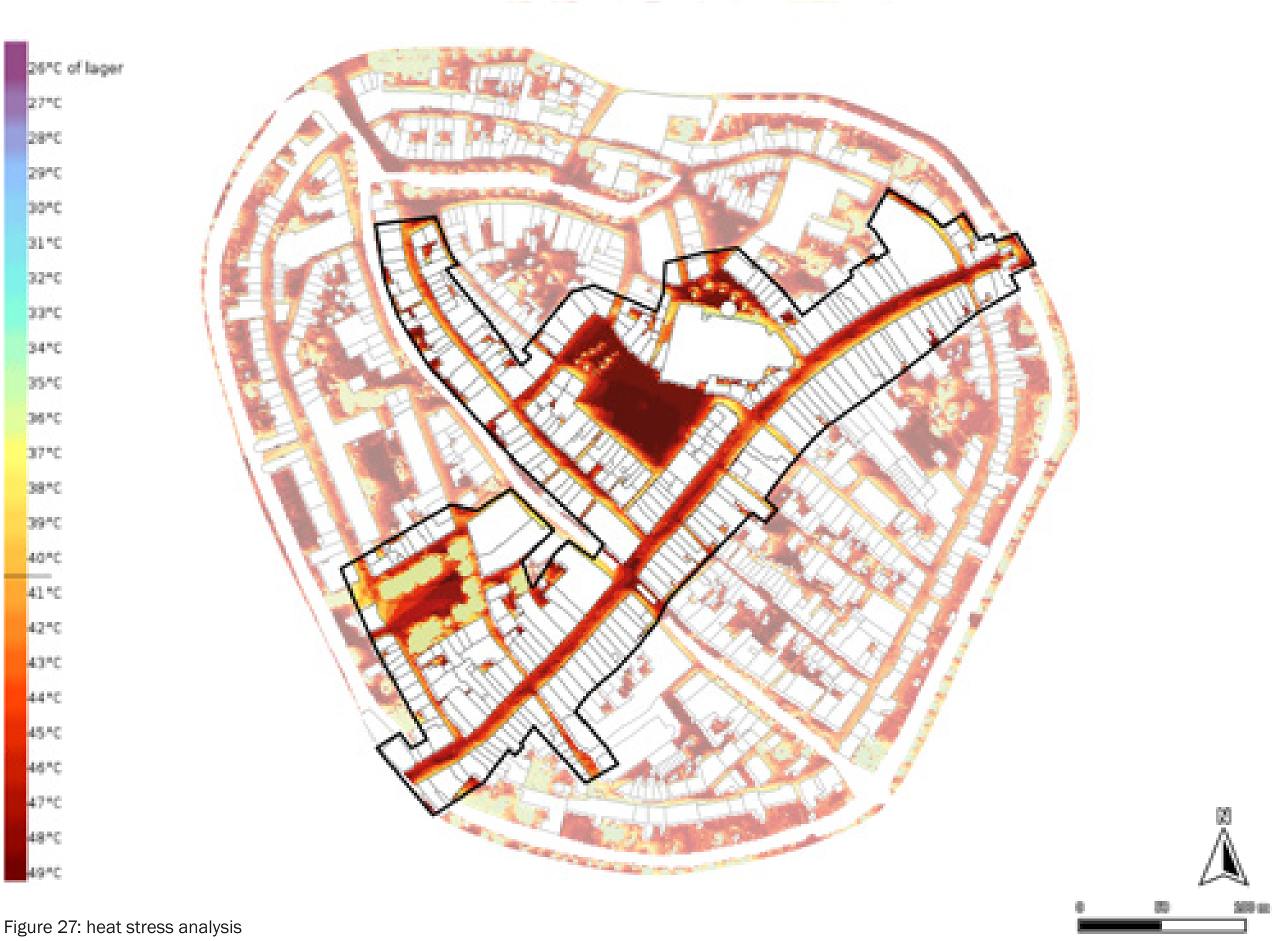


Figure 27: heat stress analysis

Figure 28: rainwater nuisance analysis

Figure 29: listed buildings

Figure 30: building typologies

6.2. Masterplan

The interventions in the wide street are mostly orientated towards the side with south-facing facades, as the analysis showed that most heat stress occurs on that side. On the other side of the wide street, an open, 3,5m wide paved lane provides good accessibility for people with difficulties walking, trucks and emergency vehicles. In between the paved lane and the shop facades, at least 1,25m remains open at all times for improved accessibility. Throughout the wide street, temporary parking spaces for electric delivery vans and a few larger parking spaces for trucks are distributed. During most parts of the day, however, the shopping streets are not accessible for vehicles. Greenery elements, such as trees in different crown sizes and concrete planters, are clustered to tackle hotspots of heat stress and rainwater nuisance. In the narrow street, an open 3,5m wide lane is located mostly in the middle of the street, as the narrow width limits the possibility of an alternate layout. In the smallest of narrow streets, where car access is very infrequent, full semi-permeable paving is implemented to tackle rainwater nuisance. On the three squares, gravel is used to cool down surface temperature and enable rainwater infiltration. The square on the southwest side of the site, has the contours of a former church integrated into the gravel paving, which is currently already the case in the conventional paving of the square. On the central square within the site, conventional paving connects several adjacent routes. Green roofs and green facades are implemented on the non-listed buildings, to tackle surface runoff of rainwater and provide cooling.


Greenery planters
Shading device
Green pergola
Trees (small crown)
Trees (large crown)
Water square
Green roof
Parasol
Temporary parking (truck)
Temporary parking (van)
N
0
50
100 m

6.2.1. Masterplan – microclimatic evaluation

In order to design and test different configurations of climate-resilient interventions with regard to microclimatic effects, the 'Climate-proof City Toolbox' was used. In figures X to X, the output is shown. This chapter shows the microclimatic evaluation for the whole study area. From chapter 6.3 onwards, a zoomed-in toolbox output is provided for each shopping street typology.

Figure 31: An overview of all interventions and their effect in numbers

In Figure 31, the output from the 'Climate-proof City Toolbox' is shown. On the left, the interventions can be seen. On the map, a yellow outline shows the study area. Moreover, the locations of each of the interventions are shown. The input for the tool is in line with the masterplan. On the right, the results are shown in several data. The data is relative to the current situation. For this thesis, the most relevant numbers are a water storage capacity of 2552m3, a groundwater recharge of 84,96 mm/year, evapotranspiration of 86,16 mm/year and an air temperature reduction of 0,82 °C

Figure 32: The PET of the current situation, without interventions

The toolbox uses the current PET as a base for calculations. The PET implications are previously addressed in the analysis as presented in chapter 6.

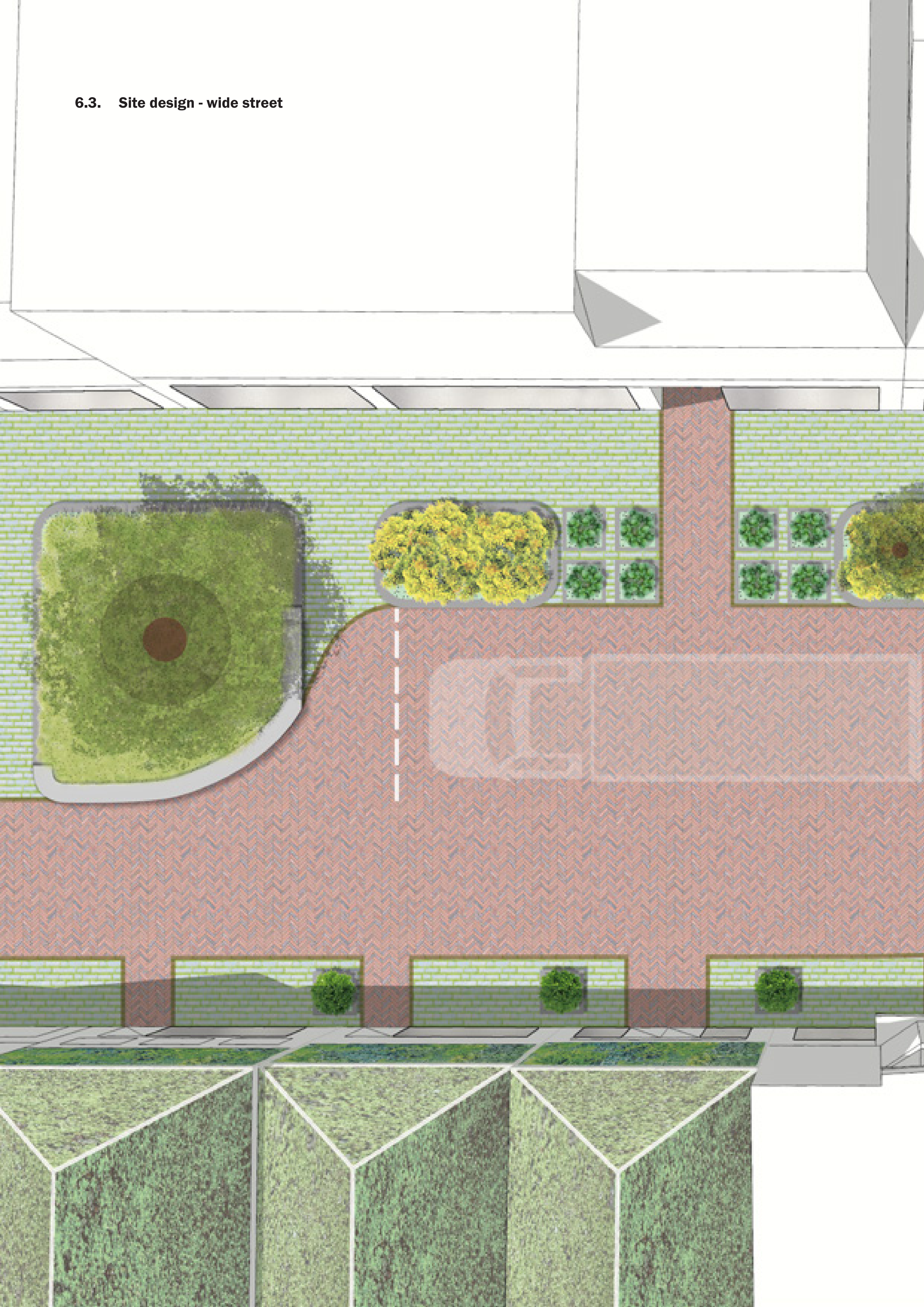
Figure 33: The PET of the situation with the site design implemented

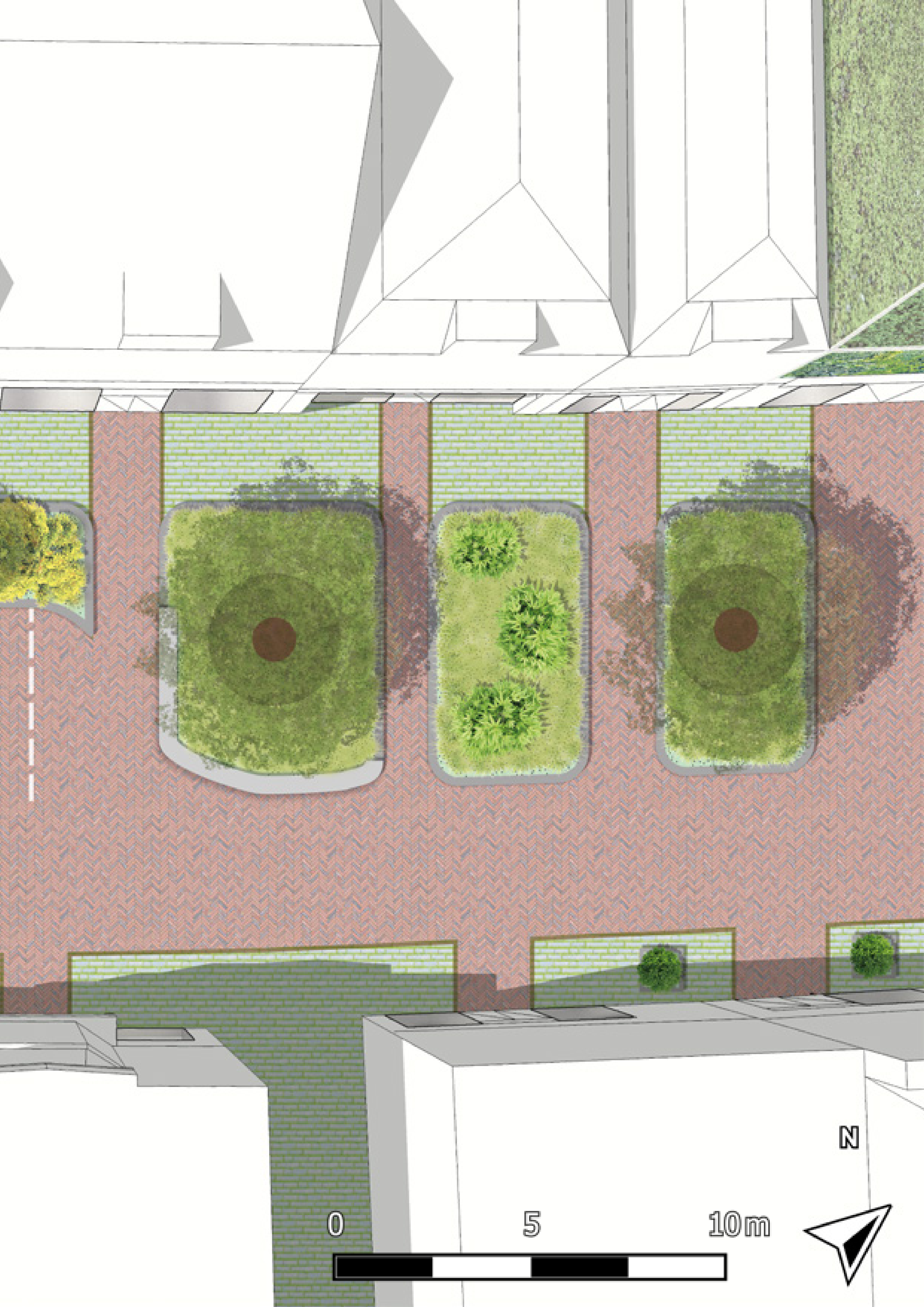
The new PET with the interventions implemented is shown in Figure 33. As can be seen, the overall PET reduction is 2,33 °C across the study area. Overall, all shopping street typologies show large areas with lower PET's. This is more clearly visible in Figure 34, which shows the difference in PET between the before and after interventions scenarios. In the following sub-sections, the microclimatic effect is addressed per shopping street typology, where local effects are clearer. The overall PET difference of 2,33 °C does not completely justify the actual cooling effect.

Figure 34: The PET difference between the situation without and with the site design implemented

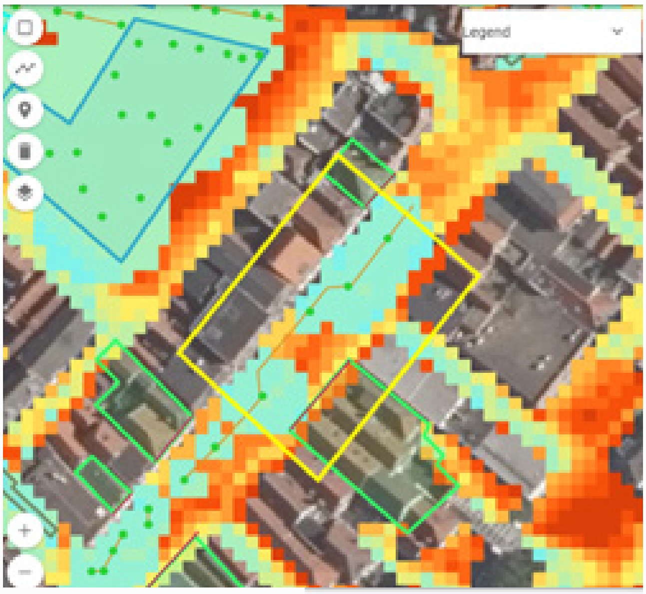
As a large surface area of the study area consists of rooftops from listed buildings, thus without interventions, a larger cooling effect can be seen on street level. This is illustrated in the microclimatic evaluations per site design, as can be seen in the following sections.

6.3. Site design - wide street




N
0
5
10m

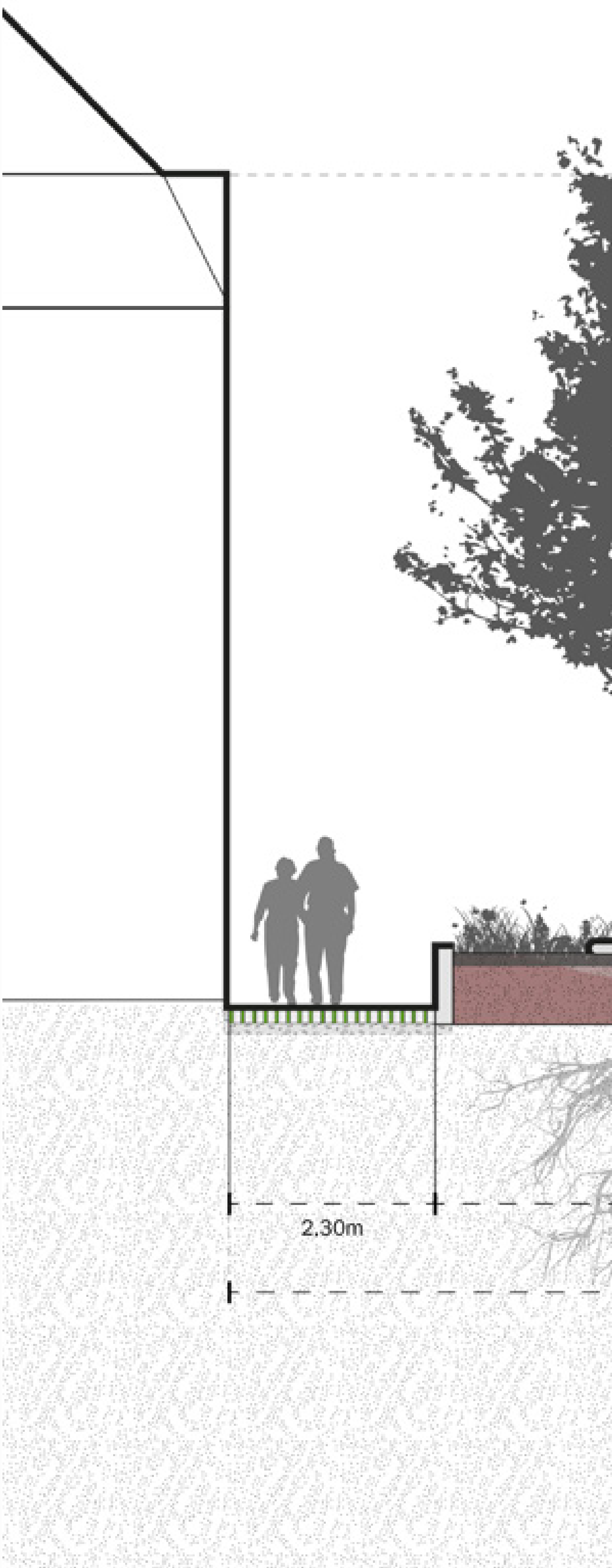
6.3.1. Wide street - microclimatic evaluation and section

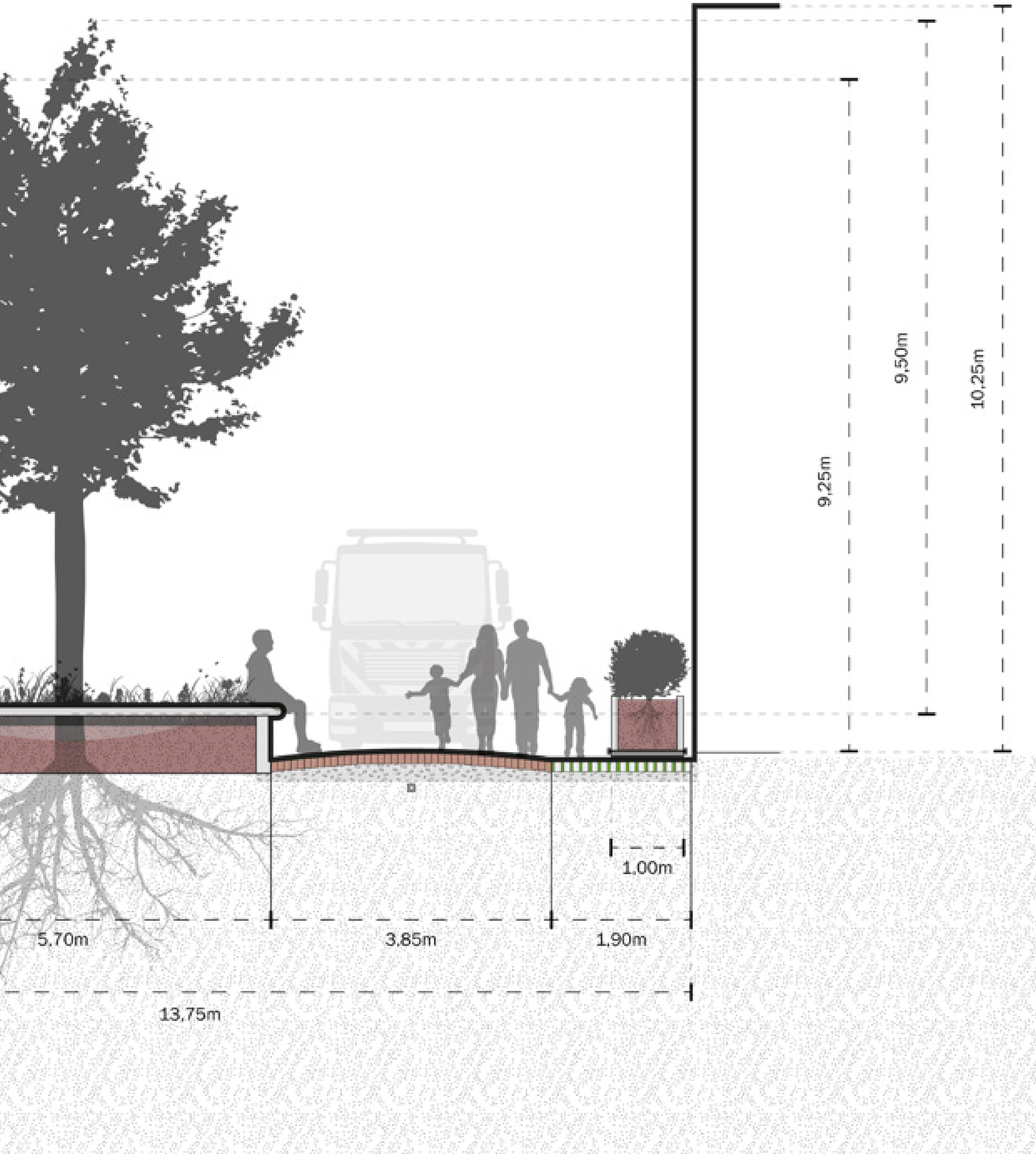


The wide street shows a PET reduction of 5,21 °C. This corresponds to the decrease of one heat stress category, which is now on the boundary between moderate and strong heat stress. As a large parking space for a truck is present within the site, some higher PET's are located around this space. However, the wide street offers a large surface area with a lowered PET overall for people to seek shelter from extreme heat.

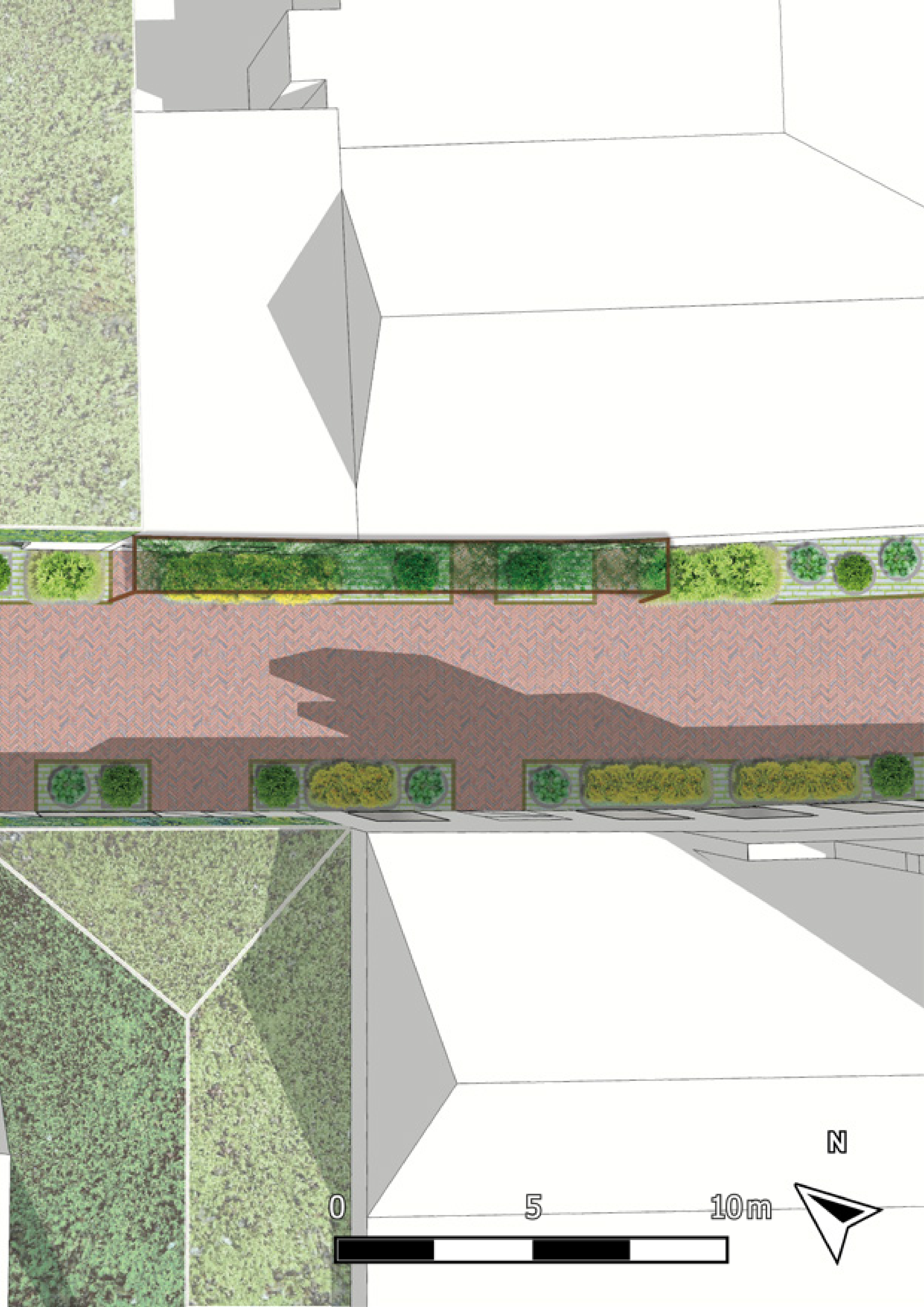
The wide street site design shows a location where a 12,5m by 4,5m sized parking space is implemented for a truck to park. Moveable planters which are placed on the northern edge of the parking space can be moved onto the space during the day. This way, the open space becomes more pleasant for customers in times when the space is not used for shop supply. The parking space has rounded corners that connect with the paved lane, to enable good access during parking. Concrete planters are the base for low vegetation, shrubs and/or trees, with some wider edges to be used for seating. Conventional clinkers connect the paved lane to each of the shops, to ensure good accessibility for all users. The edge in between conventional clinkers and semi-permeable paving is marked with an inlay of Corten steel, to cover the transition. On several buildings, green roofs and green facades have been implemented.

The conventional paving is slightly arched, to direct surface runoff to the semi-permeable paving for infiltration. Trees get space to root deeply, to ensure their health and longevity. Concrete planters are in direct connection with the soil underneath for infiltration, whereas moveable planters offer flexibility in tighter spaces.




9,25m
9,50m
10,25m
1.00m
5.70m
3.85m
1,90m
13,75m

6.4. Site design - narrow street


N
0
5
10m

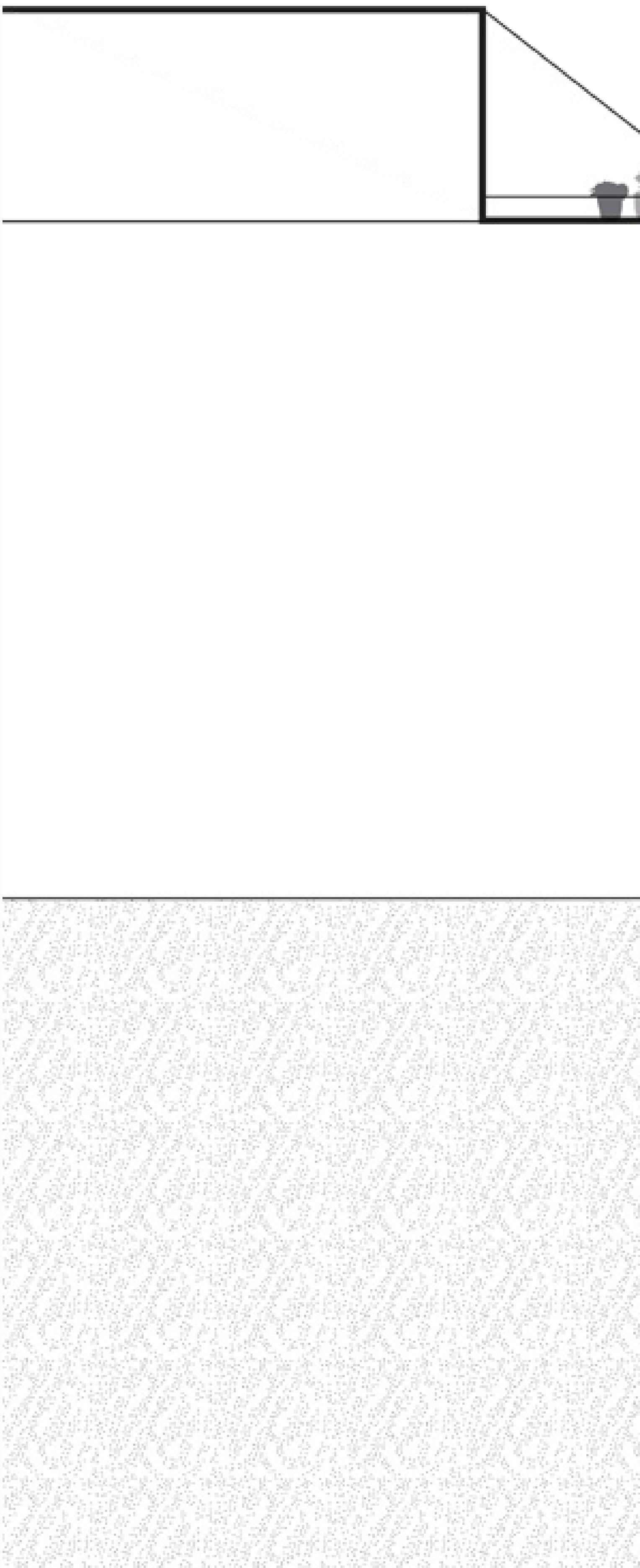
6.4.1. Narrow street - microclimatic evaluation and section

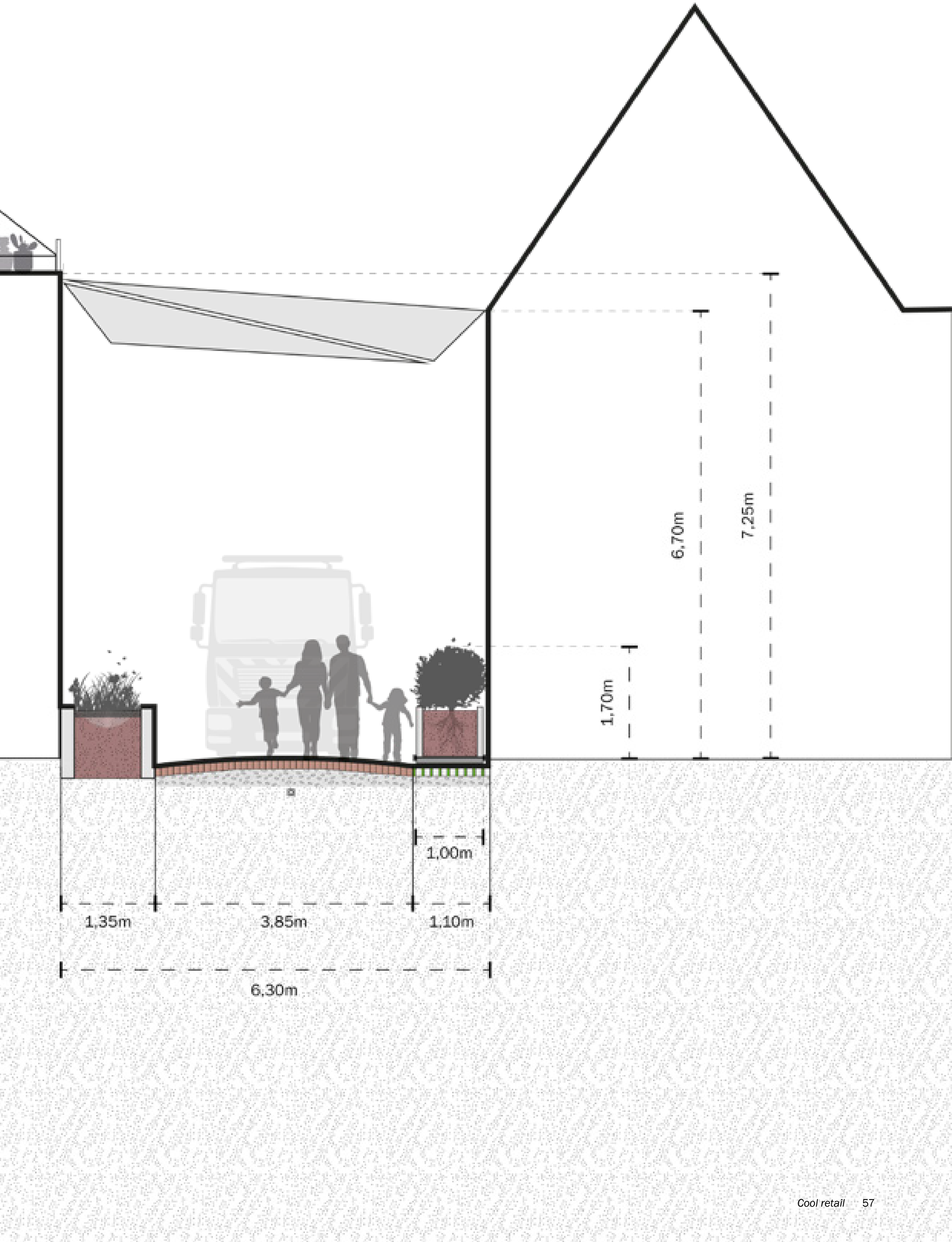
The narrow street shows a PET reduction of 2,71 °C. This corresponds the moderate heat stress category.

The PET reduction is the lowest in comparison with the other shopping street typologies, but the absolute PET is also the lowest. This is due to the small street canyon offering quite some protection from solar radiation.

The narrow street site design shows a location where a shading cover and a pergola provide shade. The open, 3,5m wide clinker lane is flanked by two sides of semi-permeable paving with concrete planters and moveable planters. Green roofs, green facades and a green balcony provide cooling and help to control superficial runoff.

The small width of the narrow street limits the size of interventions. Therefore, no trees can be implemented for example. Fixed concrete planters and moveable planters provide evapotranspiration from their low vegetation and shrubs. A shading cover tackles one of the hotspots of heat stress.

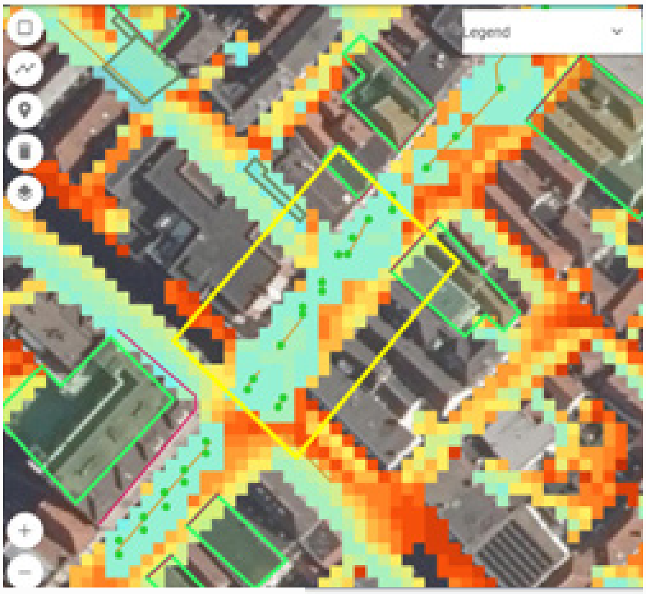



7,25m
6,70m
1,70m
1,00m
1,35m
3,85m
1.10m
6,30m

6.5. Site design - crossing


N
0
5
10m

6.5.1. Crossing - microclimatic evaluation and section

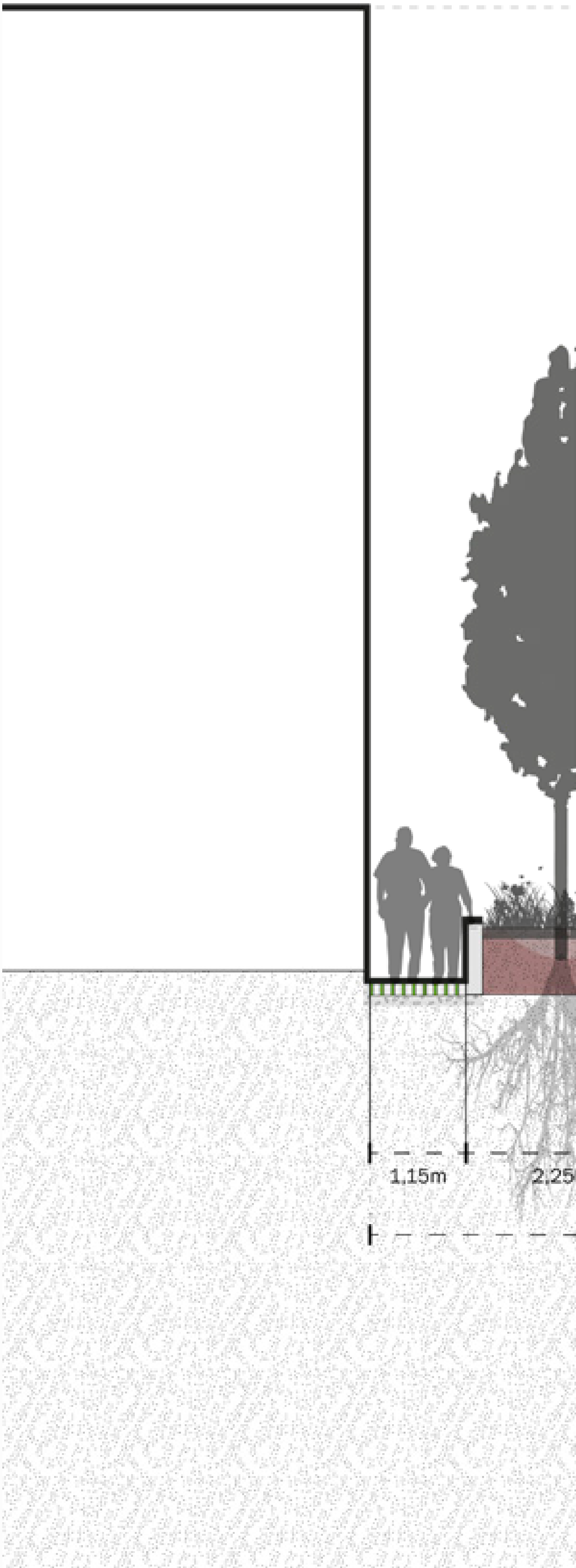


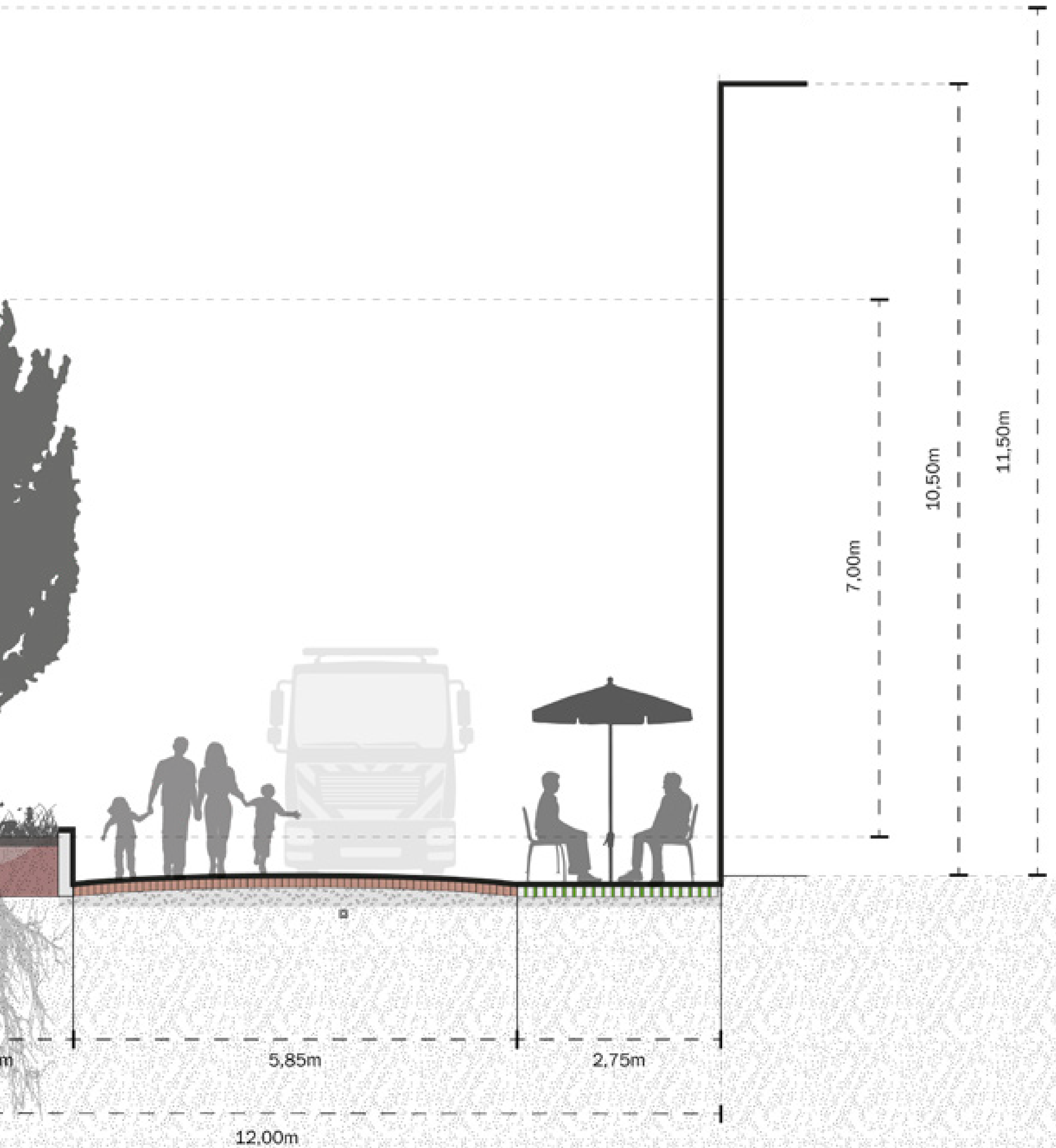
The crossing shows a PET reduction of 5,39 °C. This corresponds to the decrease of one heat stress category, which results in the strong heat stress category.

The site contains some areas without interventions, such as part of a canal and narrow corners where possibilities are limited. Overall, the crossing offers the opportunity for people to pass through along a route of low PET areas.

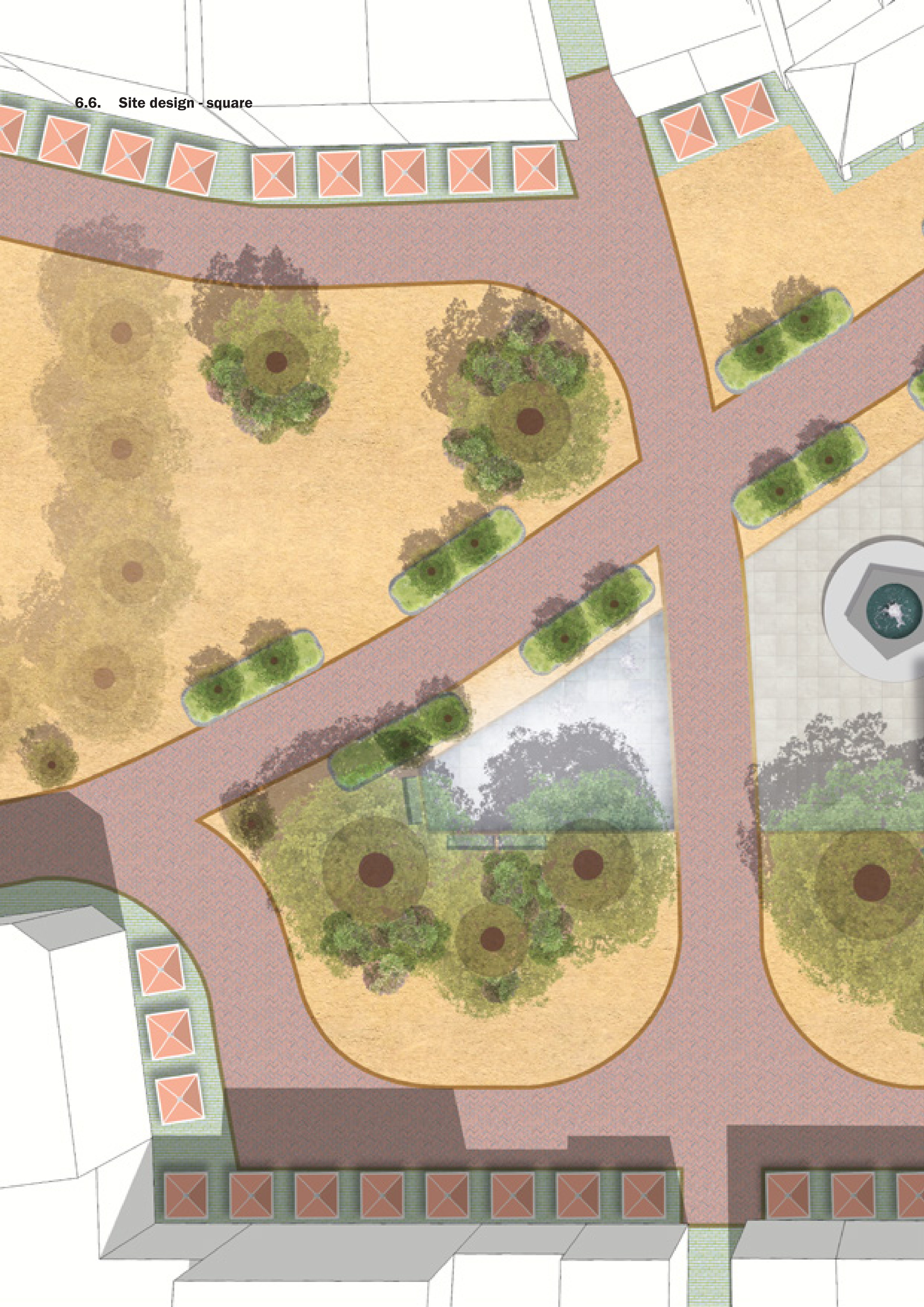
The crossing site design shows a location where the wide street connects with the narrow street. Open, rounded corners of clinkers enable the turning radius for emergency vehicles or trucks. A green archway highlights the street entrance of the narrow street, to indicate the extent of the shopping area to the shopping public. Several benches provide opportunities for people to sit down.

Within the crossing section, a larger width of conventional paving can be seen. This is due to the wide corner that connects the wide street and narrow street. Here, a smaller tree crown is implemented, to enable the implementation of a tree in limited available space. One of the cafes has a terrace in front of their façade, in the space between the façade and the open, paved lane.



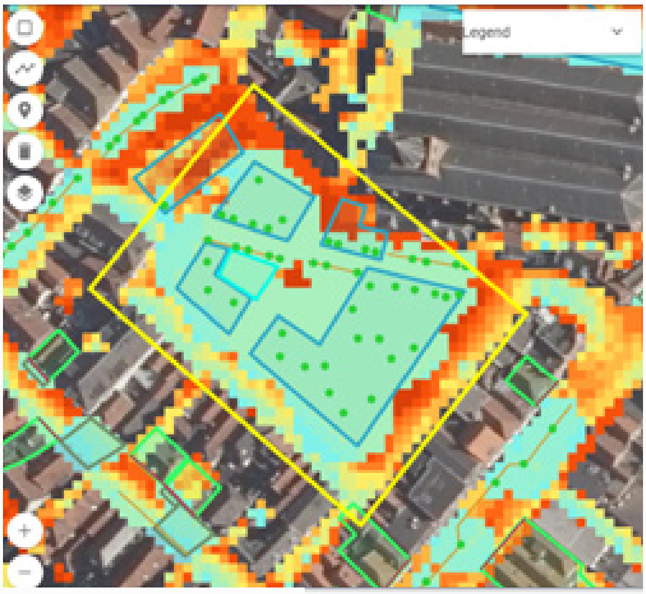

11,50m
10,50m
7,00m
m
5,85m
2,75m
12,00m

6.6. Site design - square



N
0
5
10m

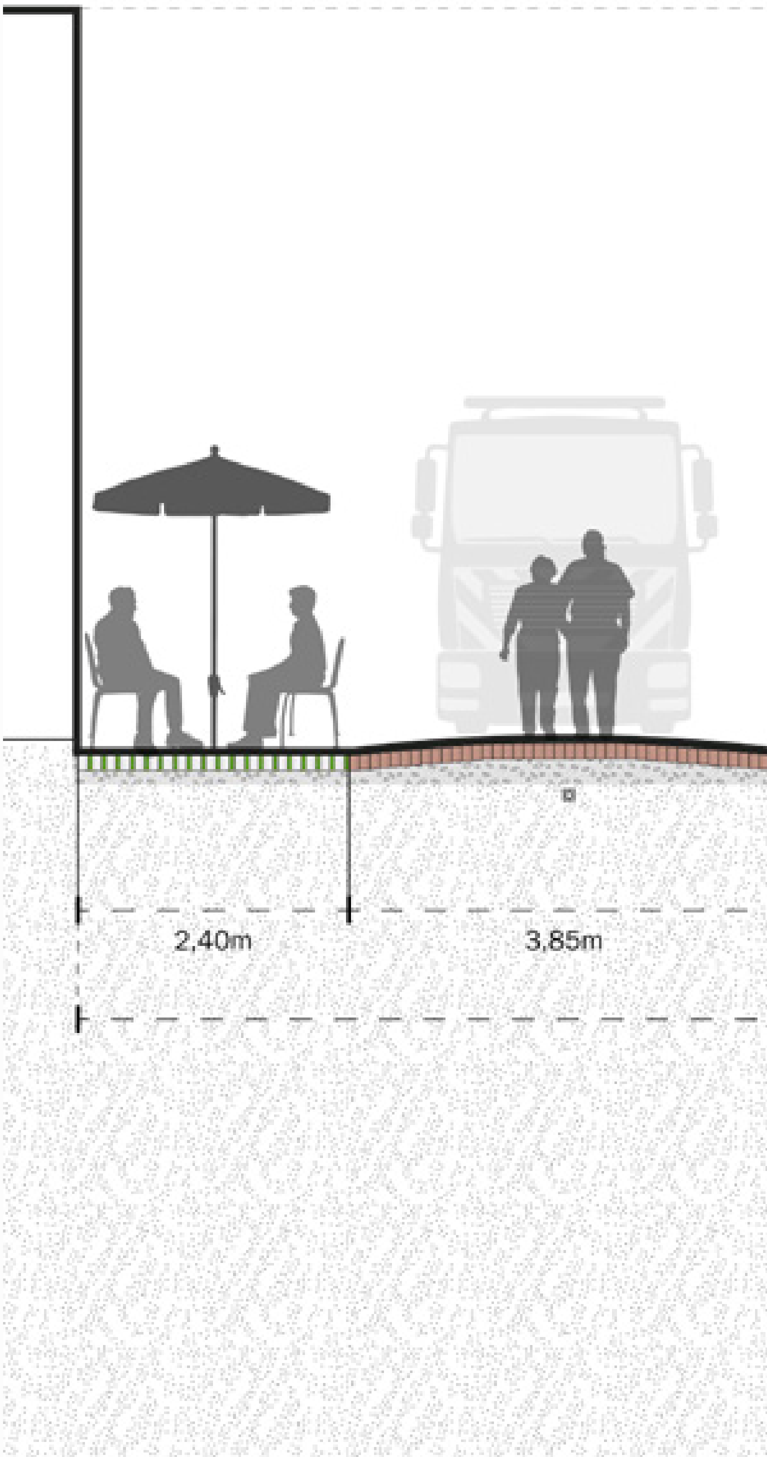
6.6.1. Square - microclimatic evaluation and section

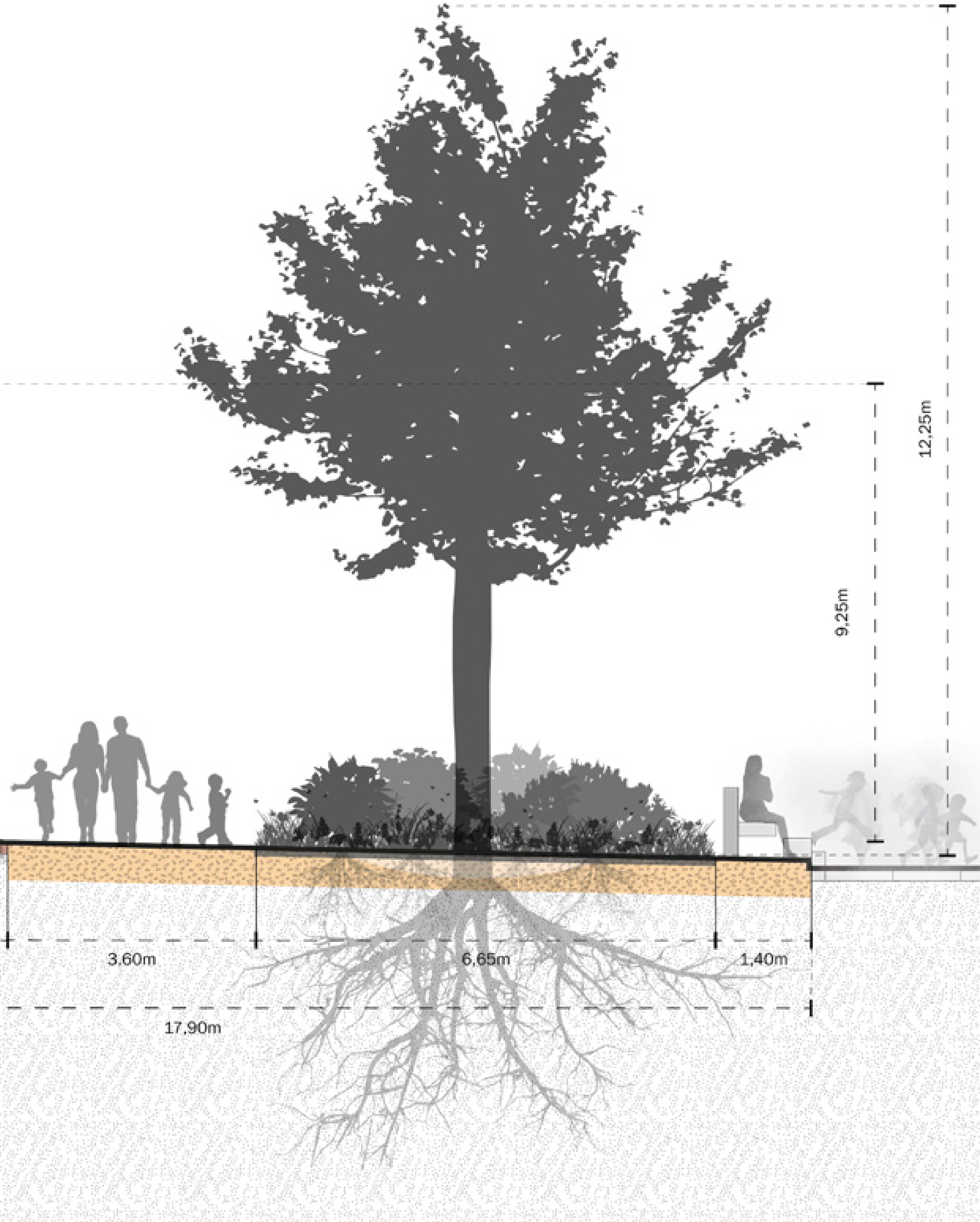


The square shows a PET reduction of 6,8 °C. This corresponds to the decrease of one heat stress category, which results in the strong heat stress category.

The square was the typology with highest initial PET. Clusters of greenery greatly reduce heat, whilst the building facades have some hotspots of heat stress. Here, parasols on the terraces can mitigate heat stress.

The square site design shows the central square within the study area. A southwest to northeast paved lane connects the narrow street with the wide street. This lane is flanked by concrete planters and small trees to highlight the connection. A paved lane along the facades enables trucks to move around the square, with rounded corners to enable their turning radius. In between, gravel compartments provide a cool surface and enable rainwater infiltration. Centrally, the existing fountain remains in place, on a conventionally paved part of the square. Here, a podium or other forms of an event can take place. To the west of this fountain, an accessible fountain with water sprays is located. This fountain doubles as a water retention basin and is therefore located on the part of the square with rainwater nuisance after an extreme rain event. Moreover, the fountain provides cooling in its direct vicinity. Alongside the fountain, benches provide seating opportunities in the shade of large trees. These trees are placed in clusters with shrubs underneath, to provide cool spots with benches underneath. Within the open parts in between the tree clusters, terraces and the weekly market can operate. Across the square, the ground surface is slightly angled from the outer edges towards the centre. Here, the gravel surface, greenery compartments and accessible fountain deal with rainwater.




12,25m
9,25m
3,60m
6,65m
1,40m
17,90m

7

7. DISCUSSION

Through the theoretical framework and methods, this thesis has aimed to contribute valid knowledge to the academic realm. However, certain "quality standards about what research should be and how it should be conducted to qualify as research that contributes to enhancing any disciplinary knowledge base" have to be considered (van den Brink et al., 2017, p.13). Validity and reliability are two important quality standards to address (van den Brink et al., 2017). Whilst literature was used to ensure the validity and reliability of this thesis, it is important to assess this in retrospect of the research.

First of all, it is relevant to look at the research in a broader context. Climate-resilient design is emerging in popularity within the literature, as a study by Meerow and Stults (2016) has shown. When we take a look at the possible climate-resilient interventions, as addressed in SRQ1, there is a lot of literature available as well.

In terms of the climate-resilient interventions as described in SRQ1, it is important to mention that a wide range of studies was used, with many different study regions. For example, Germany, Sweden, France, Italy, Portugal, the United States, Malaysia and China are some of the foreign countries where the studies took place. Some of the regions have a similar climate to the Netherlands, whilst other regions have very different climates. The reported effects of interventions on air temperature, surface temperature and PET, can therefore deviate from the potential effect it has in the Netherlands. For example, the effect of evapotranspiration in tropical climates is very different from its effect in the temperate, maritime climate of the Netherlands. Therefore, more data from studies in the Netherlands or foreign climates that are similar to the scenario for the Netherlands in 2050 for example, are crucial for further research.

When we look at literature describing the relation between climate-resilient design and shopping streets, we can see that it is described far less in literature than possible climate-resilient interventions. Still, there are some relations between climate resilience and retail described in the literature. For example: "Reduced visibility of storefronts and signage is a major concern of merchants with regard to trees on the sidewalk" (Wolf, 2005, p.398). This was acknowledged in the interviews, as one of the shop owners mentioned when discussing dense greenery in front of shops: *Zicht op de gevels van winkelpanden is belangrijk* [visibility of shop facades is important] (Shop owner in Amersfoort, 2021). These concerns were addressed in both SRQ2 and SRQ3. Figure 35 (left) illustrates how the wide street design previously blocked a lot of the visibility of shop facades and signs, where Figure 35 (right) illustrates how this visibility has been improved.

Moreover: "Pedestrians and passing vehicles pose daily risks in terms of tree damage and [tree] health" (Wolf, 2005, p.400). Again, this was acknowledged in the interviews, as mentioned by one of the shop owners: *"Bomen in de winkelstraat zijn riskant met overhangende takken in betrekking tot passerende vrachtwagens"* [trees in the shopping streets are risky with an overhang of tree branches with trucks passing by] (Shop owner in Amersfoort, 2021). These concerns were also addressed in SRQ2 and SRQ3. Figure 37 (left) illustrates an overhang of tree branches across the main roads, which is tackled in the final design as can be seen in Figure 37 (right). Moreover, Figures 35 to 38 show how all greenery is placed in sturdy planters in the final design, as opposed to the impressions prior to the participation sessions, to ensure the longevity of greenery.

Lastly: Greenery "can reduce circulation opportunities and thereby exacerbate crowding" (Joye et al., 2010, p.62). During the interviews, this was mentioned, in the context of both emergency vehicles and people with a disability.

For example, a shop owner mentioned: Groen is *"heel mooi maar helaas praktisch erg lastig in verband met hulpdiensten bereikbaarheid"* [greenery is very nice but unfortunately tricky concerning accessibility for emergency vehicles] (Shop owner in Amersfoort, 2021).

Here too, the issues were addressed in SRQ2 and SRQ3. Figure 38 (left) illustrates how accessibility is limited by narrow openings in between greenery and a vast amount of depaving, whereas Figure 38 (right) shows how circulation for trucks and accessibilty for people with disabilities is improved with paved pathways alongside the semi-permeable paving. Overall, the knowledge gained through this thesis is either in line with or tackles issues mentioned in the few articles that cover a similar scope to this thesis.

It has to be noted that climate resilience and retail are not the only relevant parts that make up the overarching domain of urban design. "In the urban design domain, the ultimate object is the city, its parts, and the relations among parts (...) the city is divided into systems (Beirão and Duarte, 2018, p.226). Thus, shopping streets are but a node in a vast network of systems that make up the city. For example, domains such as placemaking, biodiversity, sociology and ecology are mentioned in the literature as other important domains (Brown, 2013; Garrard et al., 2017; Rowley, 1994). These domains are not considered to the same extent as climate resilience and retail, as they were not as relevant for the scope of this thesis. However, in the light of future research and potential implementation of novel, climate-resilient shopping streets, it is very relevant to consider and design for the wider spectrum of domains within urban design.

As previously stressed in this thesis, it is very important to make shopping streets climate-resilient. However, shop owners were not always fully convinced that climate-resilient interventions are needed. Marschütz et al. (2020) showed that:

> *"Historical events, embedded in local memory and identity, have a surprisingly strong impact on how climate change is perceived and acted upon today. This contributes to an awareness and sense of urgency of some climate risks (...) However, it also shifts attention away from other [climate] risks"* (Marschütz et al., 2020, p.1).

This is in line with one of the limitations of the research in this thesis. The interviews with shop owners were done in November and December, which traditionally are cold months in the Netherlands, as winter approaches. Moreover, the preceding summer of 2021 was not particularly warm. The weather was volatile, with quite a bit of rain, and both July and August were cooler than on average. Both months only had a few days above 25°C (Huiskamp, 2021). Thus, the feeling of urgency for reducing heat stress was undermined by recent events and the cold weather during the interviews. In contrast, the floodings in Valkenburg, Limburg, in the summer of 2021, did show the vulnerability of the Netherlands regarding extreme rainfall, stressing the importance of interventions regarding prolonged and heavy rain events.

However, most shop owners were generally in favour of climate resilience interventions, also regarding the reduction of heat stress. Some people were quite passionate about climate resilience overall, whilst others also embraced the synergies between climate-resilient interventions and the attractiveness of the shopping street. Shop owners mentioned: *"Beeld: fantastisch mooi"* [The overall image: beautiful] and *"meer* *groen is nodig, voor het publiek belang"* [more greenery is needed, for the public good] (Shop owner in Amersfoort, 2021).

One of the interventions, as established in SRQ1 was the water mist installation. This intervention was scored very negatively during the interviews. One of the concerns was regarding the moisture threatening product quality, whilst another concern was a lack of convincement that water mist installations are really needed, as 'our summers are not as hot as those in Southern European countries', as one of the shop owners explained. Water mist installations are more frequently used in those regions.

Another shop owner mentioned: *"Vernevelaar… gebruik zeldzaam? Eén, twee of drie keer per jaar?"* [Water mist installation… its need is rare? One, two or three times a year?] (Shop owner in Amersfoort, 2021). Therefore, whilst the overall research was not too much affected by the interviews being done in the (preceding) weather conditions as previously mentioned, some interventions that were negatively scored could have been more positively scored when the interviews would have been done during a hot, summer month. Experiencing the hot sun directly could have created a larger desire for the cooling moisture of the water mist installation. Nevertheless, for the final design, the water mist installations were removed, as illustrated in Figures 35 and 37.

Concerning the interviews, a few important aspects have to be noted. Through the theoretical framework, the methodology of participatory design was defined. Throughout the interviews, design propositions were facilitated for the shop owners, with explanations of decisions and corresponding microclimatic effects. By keeping an open mind as a designer and encouraging feedback, rather than defending each decision, there was an equal power relation between the designer and shop owner. In terms of transparency, all data was processed anonymously, meaning that there is no connection between this thesis and the identity of shop owners. This way, shop owners were encouraged to speak freely, as they cannot be held accountable for design decisions made in this thesis.

When preparing the conceptual visualisations for the interviews, all shop signs were removed from the existing situation images. This was done to ensure that the local memory and identity of shop owners would not have too much of a negative effect on the scoring of interventions. Whilst the connection of shop owners with Amersfoort as the study area is important, the thesis still needs to be representable for compact, Dutch city centres overall. A final note can be made on the scoring system for the visualisation through post-its. The shop owners perceived this as intuitive, and it helped structure the discussion. However, sometimes shop owners wrote down comments on the post-it that were not in line with the corresponding post-it colour. For example, a shop owner stuck a green post-it on an intervention, implying that it was a good idea, and then wrote some concerns on the same post-it, which would correspond to a yellow post-it. Therefore, some score colours had to be adjusted during data processing. For transparency, both the scores before and after the correction are shown in the results section.

In terms of the sample of the participation sessions, there are some discussion points. First of all, the sample size consisted of seven shop owners, for two participation sessions in total. Moreover, no shop owners for the square were involved. This can be explained by a lack of responses to the invitations for the interviews. In total, 36 shops were contacted. For 10 shops, there was a response, of which 7 shops agreed to participate. The reason for a lack of responses or turning down the invitation could be explained through two factors. First of all, the COVID-19 pandemic caused shops to be closed for prolonged periods. Therefore, their priorities were on the vitality of their shop. Secondly, as the interviews were throughout November and December, in the aftermath of a COVID-19 lockdown, shops were coping with a shortage in personnel and the pressure of the upcoming holidays. Traditionally, November and December are very busy months for shops. The three rejecting responses all mentioned either their busy schedule and/or a shortage of personnel.

Moreover, the sample only included shop owners. Other actors, such as the municipality, shop suppliers and the shopping public are very relevant to the shopping street. For this thesis, there were limited time and resources. Therefore, the shop owners were the focal point of the research. Shop owners know the shopping street very well. They know how their business is doing, they regularly receive feedback from customers and are directly in touch with shop suppliers and the municipality. Thus, shop owners have a wide array of knowledge on the shopping street and are daily present in its vicinity. Each interview was done in the shop of each shop owner or a space close by, therefore making connections between the conceptual designs and the current physical state of the shopping street very tangible. The study area for the participation sessions was Amersfoort, the Netherlands. It offers a good external validity through the frequent presence of all four shopping street typologies, the presence of problems regarding both heat stress and extreme rainfall and having a city centre with an urban morphology that is very common in the Netherlands.

To quantify the effect of the climate-resilient interventions, the 'Climate-Proof Cities Toolbox' was used to test the masterplan and site designs. The benefits are previously addressed in the methods section of this thesis, but there are however also some limitations. "Users should understand the simplicity of the model and the fact that only rough estimations of heat stress reduction can be given as the effect of the interventions on the PET is also dependent on many local characteristics" *(Brolsma, 2021).*

First of all, the toolbox calculates PET differences for raster pixels of 2*2m2 (Brolsma, 2021). Therefore, very localised effects fall outside the resolution of the model. Moreover, no distinctions are made between different plant or tree species. Lastly, the final design contains areas with gravel. Gravel was not explicitly available amongst the interventions in the tool. In contrast, gravel is included in the background data, where it is indicated to have a 0% effect on PET reduction (Brolsma, 2021). In the tool, it is most likely that gravel is considered a sub-section of permeable pavement. However, permeable pavement is reported to not affect PET as well. As previously described in SRQ1, gravel can be argued to have two effects in reducing surface temperatures: The light colour of gravel, thus having high reflective properties, in combination with its permeability, helps keep its surface temperature low (Pötz, 2016). Therefore, it is expected that gravel has some effect on lowering the PET. Another intervention in the tool is 'cool materials', describing high albedo materials. This intervention was reported in the background information tool as having PET reduction potential of 10%. Thus, gravel in the tool was implemented as an overlapping plot of both permeable paving, with no cooling properties and with rainwater infiltration properties, and 'cool material', with cooling properties and without rainwater infiltration properties. This way, the properties of gravel were replicated to the extent that the tool allows.

Overall, the designs in this thesis aim to tackle climate scenario W(H) with extremes in heat and rainfall. However, regarding design for the reduction of heat stress, the microclimate during winter can be compromised. For example, artificial enhancement of ventilation in a street can be beneficial during a heat wave but can worsen the perception of low temperatures during a cold wave (Kluck et al., 2020). Moreover, solar radiation is often perceived as pleasant during cold weather (Lenzholzer, 2015).

One of aspects to consider when choosing tree species is to choose species that are not evergreen. With the loss of leaves during winter, deciduous trees enable solar radiation to reach the ground surfaces, mitigating the perceived cold temperatures during winter (Pötz, 2016). In conclusion, the right balance between deciduous and non-deciduous greenery needs to be implemented, to ensure a shopping street during winter that is both thermally comfortable and aesthetically pleasant.

The thesis offers replicability by presenting synergies, trade-offs and design criteria for climate-resilient, novel shopping streets. They form practice-orientated design guidelines for potential implementation, which are tested in a study area with a good external validity. Therefore, the results presented in this thesis are replicable for shopping streets in other compact, Dutch city centres. However, site-specific design is always needed, as local characteristics can differ per location.

Impressions comparison - wide street

Figure 35: impressions for the wide street typology, before the participation sessions (left) and after the final design (right).

Impressions comparison - narrow street

Figure 36: impressions for the narrow street typology, before the participation sessions (left) and after the final design (right).

Impressions comparison - crossing

Figure 37: impressions for the crossing typology, before the participation sessions (left) and after the final design (right).

Impressions comparison - square

Figure 38: impressions for the square typology, before the participation sessions (left) and after the final design (right).

8

8. CONCLUSION

Designing novel, climate-resilient shopping streets that embrace synergies between climate resilience and retail functionality, whilst catering to the different actors within the public space of shopping streets, has been the aim of this thesis. Through answering each of the research questions, tensions in the shopping street revolving around the implementation of climate-resilient interventions and retail functionality were tackled. Moreover, interventions are proposed to deal with the urban climate of shopping streets concerning the future climate scenario W(H).

SRQ1: What are possible interventions to make Dutch shopping streets climate-resilient towards the W(H) climate scenario?

Through a literature study, an inventory of 18 interventions that can contribute to the climate resilience of shopping streets was made, both regarding heat stress and rainwater nuisance. Each intervention has specific benefits towards lowering heat stress and increasing rainwater infiltration capacity. Often, certain combinations, such as evapotranspiration underneath shade, can collectively enhance the climate resilience effect. Moreover, clustering climate-resilient interventions can tackle hotspots of heat stress and rainwater nuisance.

SRQ2: What are synergies and trade-offs between retail and climate resilience?

Climate-resilient interventions not only work alongside the retention of retail functionality but they can even enhance the overall shopping experience. Certain interventions, such as water mist installations, appeared to have too much of a negative effect on retail functionality. Other interventions, such as a pocket park with seating, offered additional functionality and ambiance to the shopping street. Not every climate-resilient intervention works in each shopping street typology. A pocket park does not fit in a narrow street for example. Moreover, different shop typologies combine in various ways with climate resilience interventions. Shops that heavily rely on their shop display, do not combine well with façade gardens for example, as they block the view of the shop display. On the other hand, by placing interventions on the edges between two shops, interesting sightlines can be created, that can even direct additional attention to the shop display. By implementing interventions with certain criteria in mind, like planting shrubs in concrete planters, the concurrence of an intervention with retail can be improved, making the intervention feasible in the shopping street.

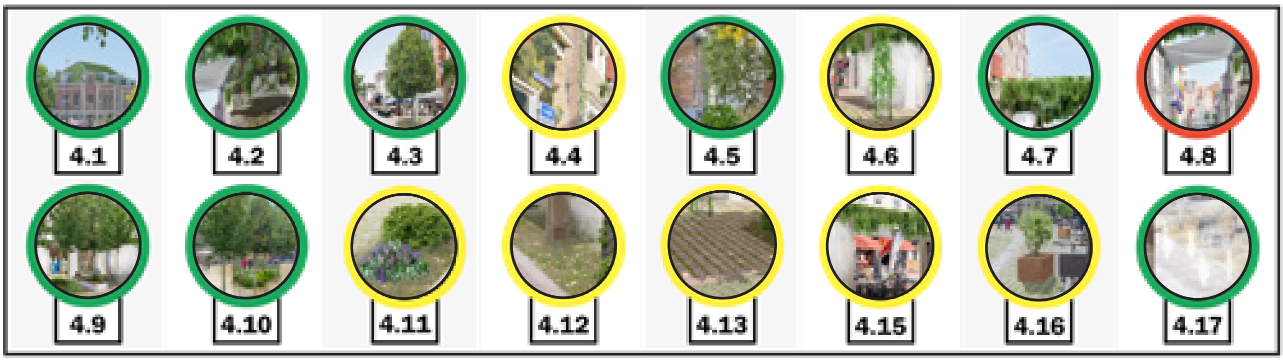
SRQ3: What is the current acceptance of shop owners towards climate-resilient interventions and how can this be improved?

Shop owners are generally in favour of more greenery in shopping streets. They have a short-term mindset, that is focused on the optimal performance of their business. Therefore, climate-resilient interventions are not on top of their priority list. However, in the right synergy with retention of the retail functionality, especially when the overall ambiance of the shopping street is enhanced, shop owners are very positive about implementing climate-resilient interventions in shopping streets. By raising awareness of climate issues in shopping streets, taking shop owners along in the design process and adhering to the design criteria that were derived from the participation sessions as presented in this thesis, the acceptance of shop owners towards climate-resilient interventions can be obtained and even be improved.

MRQ: How can Dutch shopping streets be made climate-resilient?

There is a range of possible climate resilience interventions for Dutch shopping streets. By designing shopping streets with the right combinations of climate resilience interventions and the existing shopping street layout, a more climate-resilient shopping street can be attained. Furthermore, the inclusion of shop owners in the design process will result in novel shopping streets that fit the required retail functionality and ambiance that shop owners strive for. Overall, the thesis shows that complex, compact Dutch city centres that largely consist of shopping streets, can be made climate-resilient whilst retaining and even enhancing the possibilities that shopping streets offer for shop owners and their customers.

Step 1. Determine which interventions are possible and how they concur with retail functionality.



Step 2. Improve the concurrence of the interventions with retail funtionality.

4.1
- Not on monuments

4.2
- Stimulate the use of plants on balconies

4.3
- Make clusters
- Alternate tree crown sizes

4.4
- Do not cover architectural features
- Inspect facade

4.5
- Provide protection around plant bases

4.6
- Use sturdy materials for frame

4.7
- Ensure maintenance accessiblity
- Do not cover entire street

4.8
- Do not cover entire street

4.9
- Make robust compartment

4.10
- Use in large spaces

4.11
- Implement in sturdy planters

4.12
- Implement in sturdy planters

4.13
- Apply alongside main walking routes

4.15
- Ensure sufficient height for shop visibility

4.16
- Make them moveable

4.17
- Use as rainwater retention basin

Step 3. Determine where the interventions can be implemented in the shopping street.

4.1
- All street typologies
- All building typologies

4.2
- All street typologies
- All building typologies

4.3
- Wide street
- Crossing
- Square
- No display
- Plain facade
- Horeca clear
- Building side

4.4
- All street typologies
- Plain facade
- Building side

4.5
- Narrow street
- Building side

4.6
- Wide street
- Crossing
- Square
- No display
- Horeca clear
- Building side

4.7
- Narrow street
- Display
- No display
- Plain facade
- Detail facade
- Horeca clear
- Building side

4.8
- Narrow street
- Display
- No display
- Plain facade
- Detail facade
- Horeca clear
- Building side

4.9
- Crossing
- Square
- No display
- Building side

4.10
- Square
- No display
- Building side

4.11
- Wide street
- Crossing
- Square
- All building typologies

4.12
- Wide street
- Crossing
- Square
- All building typologies

4.13
- All street typologies
- All building typologies

4.15
- All street typologies
- No display
- Plain facade
- Horeca clear
- Building side

4.16
- All street typologies
- Display
- No display
- Horeca clear
- Building side

4.17
- Square
- Building side

Step 4. Adhere to design criteria when implementing the interventions in the shopping street.

- Orientate interventions towards dominant, summer solar direction
- Ensure sufficient seating elements
- Ensure accessible surface area for all users
- Highlight street entrances
- Ensure sufficient accessiblity of shop entrances
- 3,5m wide open street with turning radius for emergency vehicles
- Ensure visibility of shop facades, signage and architecture
- Create suprising views and route in the streetscape
- Make spaces that are flexible and can host different functions
- Urban features should be vandalism-proof
- The public space should be neat, organised and coherent
- Create parking compartment hubs with several larger parking spaces

Figure 39: practice-orientated design guidelines for potential implementation

As described in the methods section, this thesis has opted to provide practice-orientated design guidelines for potential implementation, as can be seen in Figure 39. The answers to each research question and conclusions derived from the interviews, form guidelines for the potential implementation of climate-resilient interventions in shopping streets. Based on the outcomes of the sub-research questions tackled in this thesis, the guidelines consist of the following four steps:

Step 1. Determine which interventions are possible and how they concur with retail functionality.

16 possible interventions were identified in this thesis and are presented in Figure 39. For each of the 16 included interventions, the scores from the participation sessions are shown. The corresponding numbers refer to the sub-chapters as described in chapter 4. By making an inventory of the possible interventions and evaluating their synergy with retail, a selection can be made of climate-resilient interventions that can work in the shopping street.

Step 2. Improve the concurrence of the interventions with retail funtionality.

Some interventions need little alterations for implementation, whilst others have some specific guidelines to improve their concurrence with retail functionality. Therefore, specific guidelines for each intervention are defined in Figure 39. Whilst previously some interventions might have raised concerns regarding their concurrence with retail functionality, these guidelines can help to improve the applicability of each intervention within the shopping street.

Step 3. Determine where the interventions can be implemented in the shopping street.

Each intervention has certain street typologies where they work with the spatial dimensions, as well as certain building typologies that they combine well with. For the third step, Figure 39 illustrates where the climate-resilient interventions can be applied within shopping streets. By carefully analysing the shopping street and building typologies of the study area during a project, the possible interventions for each location can be narrowed down.

Step 4. Adhere to design criteria when implementing the interventions in the shopping street.

For the final step, criteria for the overall implementation are defined. These criteria should always be considered, to ensure that climate-resilient interventions work well with the retail functionality of the shopping street.

Overall, these practice-orientated design guidelines for the potential implementation of climate-resilient interventions summarise the main takeaways from this thesis. By taking the design guidelines into account when considering climate-resilient interventions in a shopping street, the overall acceptance and functionality of these interventions can be achieved.

Still, as described throughout the discussion, there are limitations to this thesis, which need to be considered when interpreting these design guidelines.

Future research is needed across several domains that were addressed in this thesis. Firstly, more intensive microclimatic evaluations of climate-resilient interventions are needed to get more accurate data on the implications.

The ‘Climate-Proof Cities Toolbox’ was very convenient for the limited time and resources within this thesis but does not provide the accuracy that a tool such ENVI-met can provide. More intensive microclimate simulations are needed to ensure that implemented climate-resilient interventions will provide the desired effect in the real world.

Secondly, it is important to explore synergies between climate resilience, retail functionality and other domains. These domains can include but are not limited to, as mentioned in the discussion chapter: placemaking, biodiversity, sociology and ecology. The city should be resilient throughout the entire system. Moreover, by linking climate resilience and retail functionality to other domains, larger support for the potential implementation of interventions can be created.

Thirdly, more studies and larger sample sizes are needed to increase the validity of the findings in this thesis. The research in this thesis indicates the potential and need for climate-resilient interventions in shopping streets, but it is difficult to strongly argue for design guidelines based on one study area with limited sample size.

Fourthly, future research should include more and/or other instances, such as but not limited to: municipalities, design and microclimate experts, shop suppliers and the shopping public. Each stakeholder has different ideas and concerns regarding shopping streets, which can contribute to a more holistic debate.

Lastly, future research is needed to contribute to a wider range of design guidelines whilst increasing the overall validity of these guidelines.

To conclude, it needs to be stressed that this thesis aims to inspire everyone that works in a field related to or is interested in topics within the scope of this thesis. The research performed in this thesis acknowledges that there are limitations and difficulties regarding the implementation of climate-resilient interventions in shopping streets. However, as experienced throughout the research, the author would like to stress the surge of enthusiasm that people have expressed regarding climate-resilient, novel shopping streets. Policymakers can get caught up in an entanglement of practical objections when it comes to innovation. This thesis aims to ignite the discussion and the development of feasible solutions to resolving heat stress and rainwater nuisance within shopping streets. The author truly believes that, through collective effort, climate-resilient, novel shopping streets in compact, Dutch city centres are very much a thing of the (near) future. In combination with other climate resilience initiatives, the city can retain its desire and develop greater resilience to the changes that the future holds.

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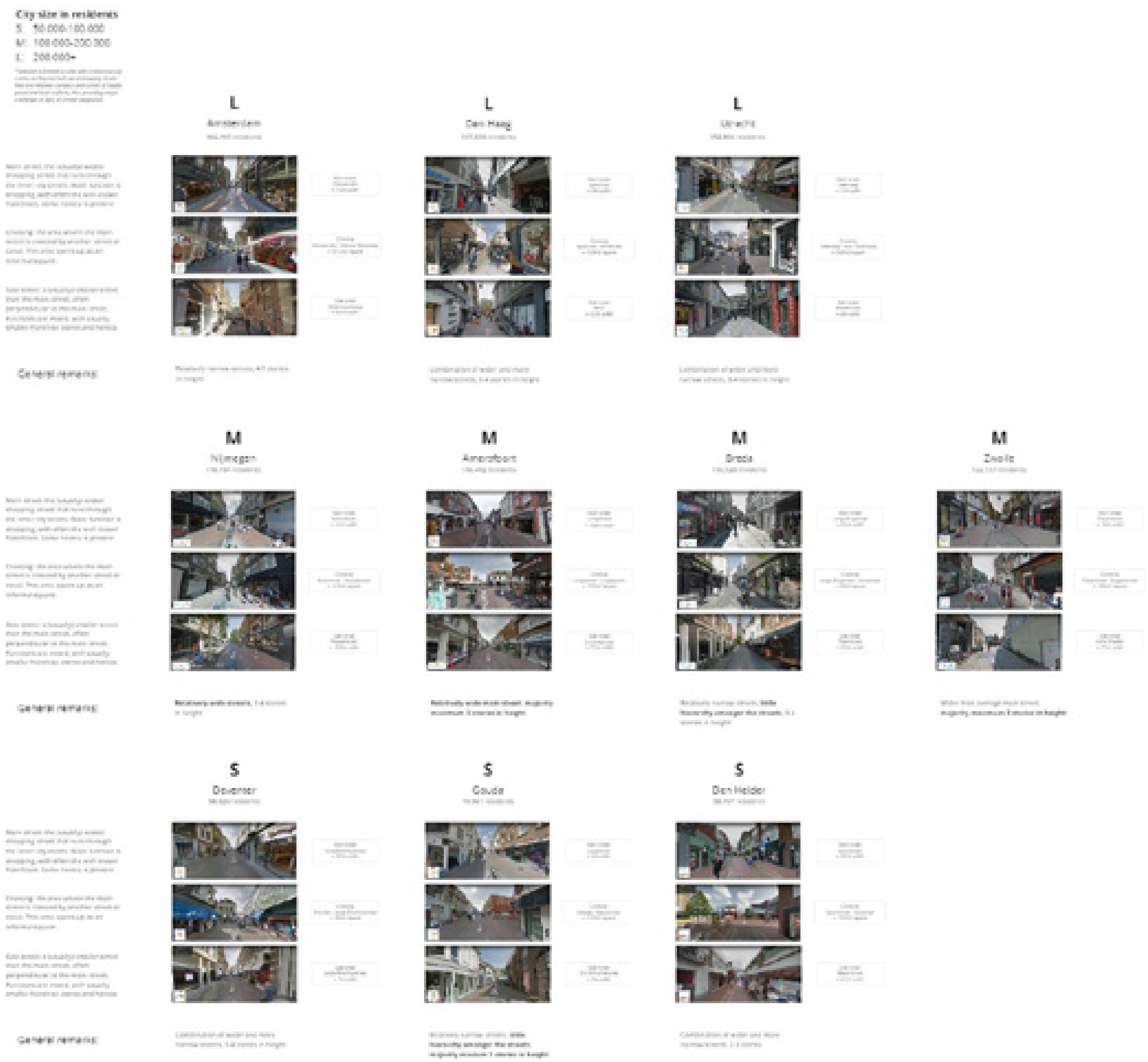
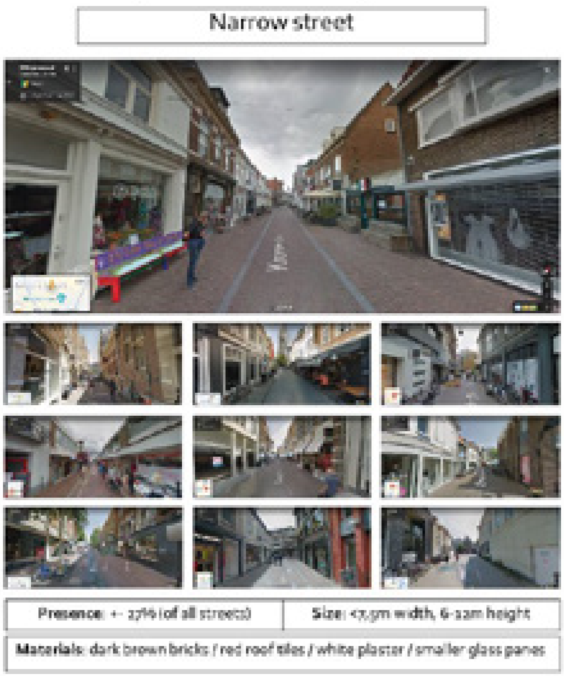
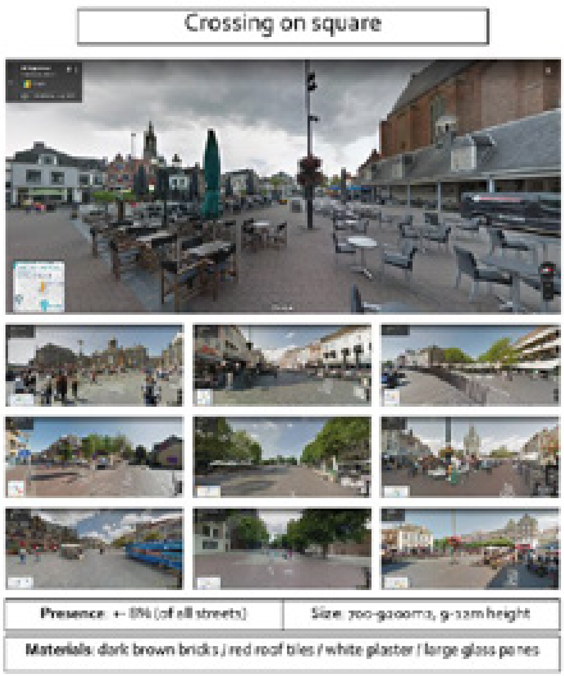
APPENDIX

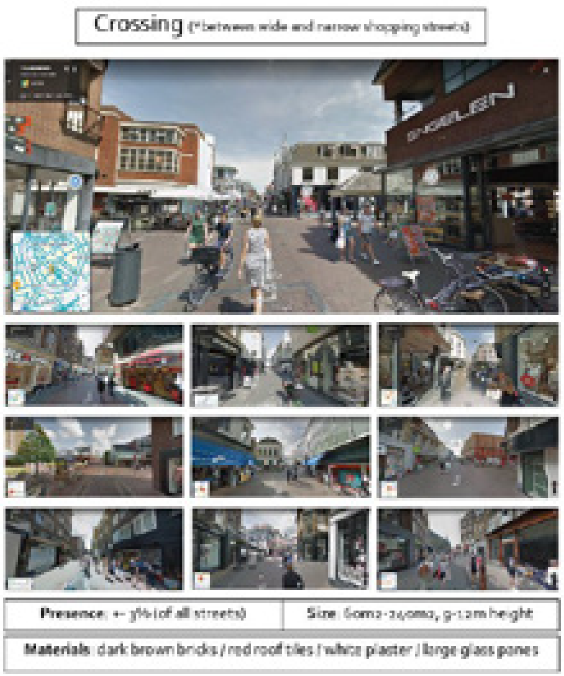
Preliminary analysis: Compact Dutch city centres consist mainly of shopping streets



Preliminary analysis: Compact Dutch city centres consist mainly of four shopping street typologies

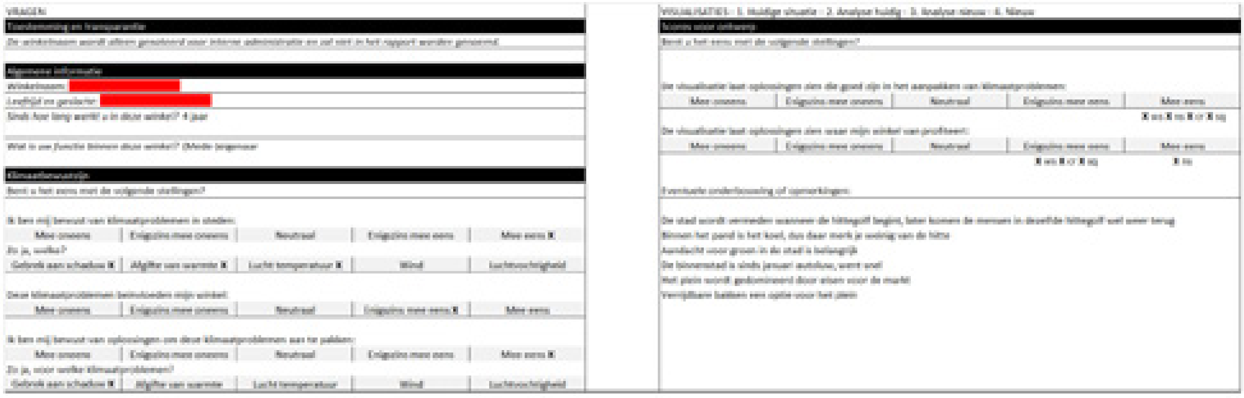


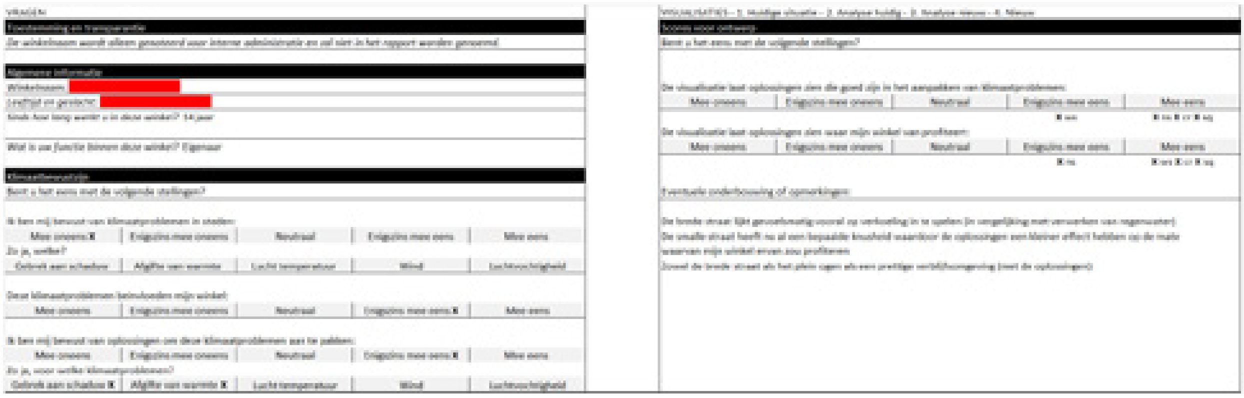


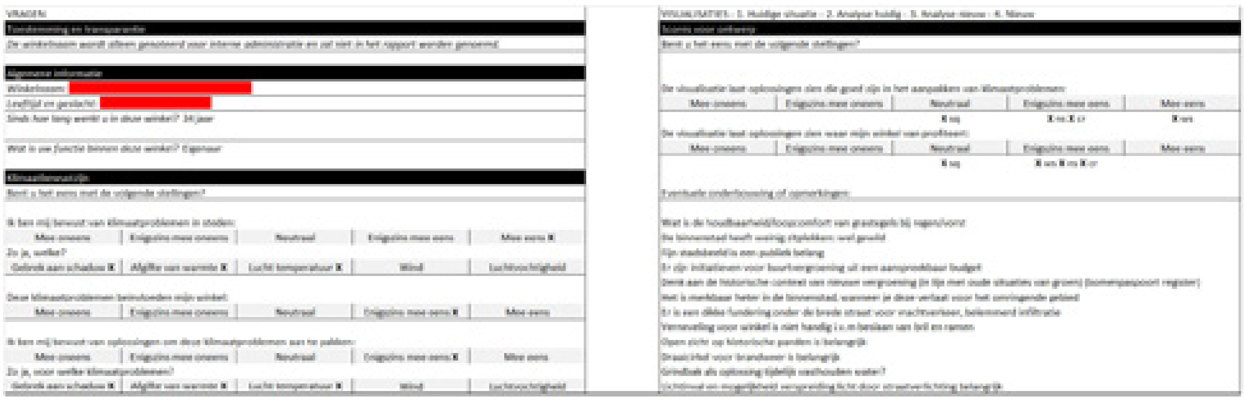


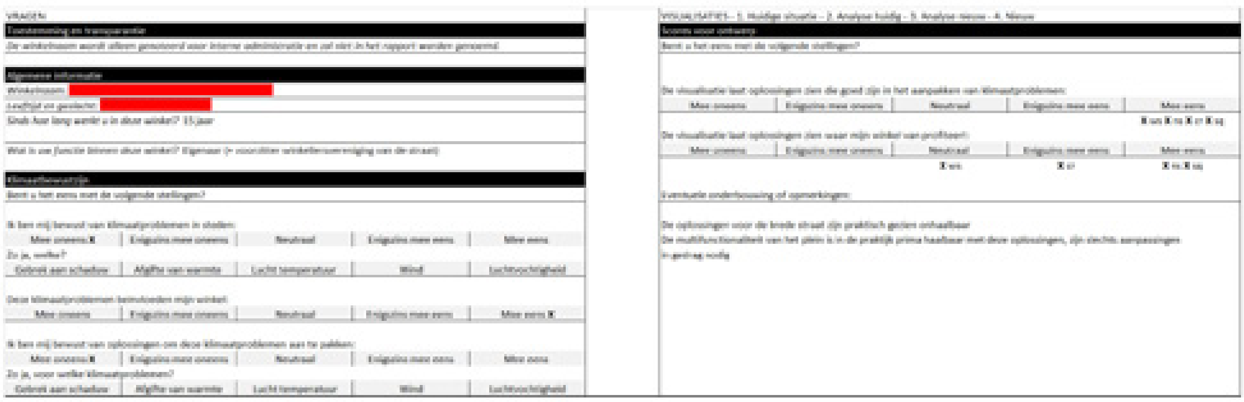
Interview outcomes session 1 - answers to interview questions

(Shop) names, age and gender are crossed out for anonymity reasons









Interview outcomes session 1 - answers to interview questions and data analysis

(Shop) names, age and gender are crossed out for anonymity reasons

VRAGEN

Toestemming en transparantie

De winkelnaam wordt alleen genoteerd voor interne administratie en zal niet in het rapport worden genoemd.

Algemene informatie

Winkelnaam: [redacted]

Leeftijd en geslacht: [redacted]

Sinds hoe lang werkt u in deze winkel? 6 jaar

Wat is uw functie binnen deze winkel? (Mede-)eigenaar

Klimaatbewustzijn

Bent u het eens met de volgende stellingen?

Ik ben mij bewust van klimaatproblemen in steden:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens X	Mee eens

Zo ja, welke?

Gebrek aan schaduw X	Afgifte van warmte X	Lucht temperatuur X	Wind X	Luchtvochtigheid

Deze klimaatproblemen beïnvloeden mijn winkel:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens X

Ik ben mij bewust van oplossingen om deze klimaatproblemen aan te pakken:

Mee oneens X	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens

Zo ja, voor welke klimaatproblemen?

Gebrek aan schaduw	Afgifte van warmte	Lucht temperatuur	Wind	Luchtvochtigheid

VISUALISATIES - 1. Huidige situatie - 2. Analyse huidig - 3. Analyse nieuw - 4. Nieuw

Scores voor ontwerp

Bent u het eens met de volgende stellingen?

De visualisatie laat oplossingen zien die goed zijn in het aanpakken van klimaatproblemen:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
			X cr X sq	X ws X ns

De visualisatie laat oplossingen zien waar mijn winkel van profiteert:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
			X ws	X ns X cr X sq

Eventuele onderbouwing of opmerkingen:

In de brede straat belemmeren de perkjes de vrije looppruimte en verneveling is niet praktisch vanwege het vocht i.r.t. de producten in de winkel
Het plein mag nog meer schaduw bieden
Combinatie van beplante en bevochtigde schermen waar de wind doorheen kan waaien?
Wateroverlast voor winkel is voorgekomen, water tot aan de drempel
Wordt initiatief genomen om beplanting in de straat te realiseren, lastig vanwege fietsen en juiste omstandigheden voor planten om goed te kunnen groeien

VRAGEN

Toestemming en transparantie

De winkelnaam wordt alleen genoteerd voor interne administratie en zal niet in het rapport worden genoemd.

Algemene informatie

Winkelnaam: [redacted]

Leeftijd en geslacht: [redacted]

Sinds hoe lang werkt u in deze winkel? 14 jaar

Wat is uw functie binnen deze winkel? Eigenaar

Klimaatbewustzijn

Bent u het eens met de volgende stellingen?

Ik ben mij bewust van klimaatproblemen in steden:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens X

Zo ja, welke?

Gebrek aan schaduw X	Afgifte van warmte	Lucht temperatuur X	Wind X	Luchtvochtigheid X

Deze klimaatproblemen beïnvloeden mijn winkel:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens X	Mee eens

Ik ben mij bewust van oplossingen om deze klimaatproblemen aan te pakken:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens X	Mee eens

Zo ja, voor welke klimaatproblemen?

Gebrek aan schaduw X	Afgifte van warmte X	Lucht temperatuur	Wind	Luchtvochtigheid

VISUALISATIES - 1. Huidige situatie - 2. Analyse huidig - 3. Analyse nieuw - 4. Nieuw

Scores voor ontwerp

Bent u het eens met de volgende stellingen?

De visualisatie laat oplossingen zien die goed zijn in het aanpakken van klimaatproblemen:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
				X ws X ns X cr X sq

De visualisatie laat oplossingen zien waar mijn winkel van profiteert:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
				X ws X ns X cr X sq

Eventuele onderbouwing of opmerkingen:

Merkbaar minder klanten gedurende periode van hitte
Bomen zijn een must
Klimplanten overgroei aantrekkelijker dan schaduwdoek (in het algemeen graag meer groen)
Geveltuin veroorzaakt afval
De smalle straat is aantrekkelijker dan de brede straat vanwege het compacte/knusse karakter
Op het plein is er de voorkeur voor groene bestrating i.p.v. gravel vanwege rommelige uiterlijk/onderhoudsgevoelig

VRAGEN

Toestemming en transparantie

De winkelnaam wordt alleen genoteerd voor interne administratie en zal niet in het rapport worden genoemd.

Algemene informatie

Winkelnaam: [redacted]

Leeftijd en geslacht: [redacted]

Sinds hoe lang werkt u in deze winkel? 4 jaar

Wat is uw functie binnen deze winkel? Eigenaar

Klimaatbewustzijn

Bent u het eens met de volgende stellingen?

Ik ben mij bewust van klimaatproblemen in steden:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens X	Mee eens

Zo ja, welke?

Gebrek aan schaduw X	Afgifte van warmte	Lucht temperatuur X	Wind	Luchtvochtigheid

Deze klimaatproblemen beïnvloeden mijn winkel:

Mee oneens	Enigszins mee oneens X	Neutraal	Enigszins mee eens X	Mee eens

Ik ben mij bewust van oplossingen om deze klimaatproblemen aan te pakken:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens X	Mee eens

Zo ja, voor welke klimaatproblemen?

Gebrek aan schaduw X	Afgifte van warmte	Lucht temperatuur	Wind X	Luchtvochtigheid

VISUALISATIES - 1. Huidige situatie - 2. Analyse huidig - 3. Analyse nieuw - 4. Nieuw

Scores voor ontwerp

Bent u het eens met de volgende stellingen?

De visualisatie laat oplossingen zien die goed zijn in het aanpakken van klimaatproblemen:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
				X ws X ns X cr X sq

De visualisatie laat oplossingen zien waar mijn winkel van profiteert:

Mee oneens	Enigszins mee oneens	Neutraal	Enigszins mee eens	Mee eens
				X ws X ns X cr X sq

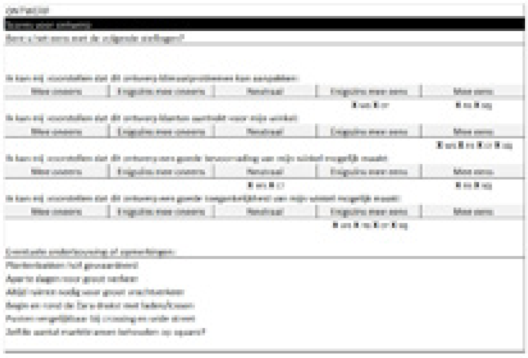
Eventuele onderbouwing of opmerkingen:

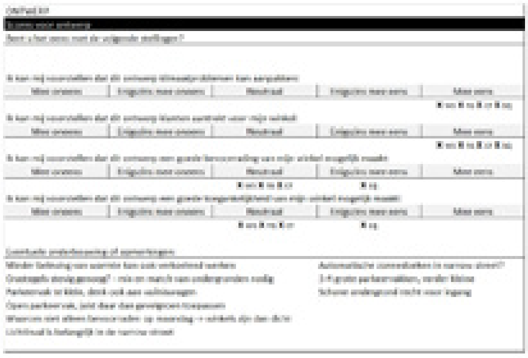
Weinig last van klimaat: cool en beschaduwd deel van de Langestraat
Minder klanten gedurende hittegolf
Worden grastegels gladder dan gewone bestrating?
Winkel is afhankelijk van koeltetransport: mogelijk met kleine busjes?
Thermometer aan de overkant van de straat: 47,6 graden (27 juli 2018 om 14:00)
Verkeersveiligheid door veranderingen in winkelstraat beter
Groen creert een verblijfsplek die mensen langer vasthoudt
Er is te weinig stimulans (€) voor groene daken, dus te duur voor veel mensen
Maak een gevarieerde reeks van schaduwdoeken en groene overgroei
Klimplant structuren hoger en/of als boog over de straat entrees

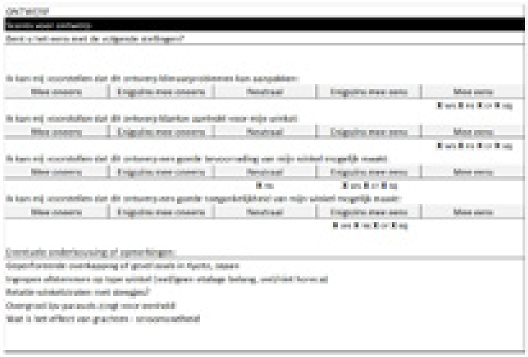
Sample:							
Sample size:	7						
Shop types:	Lunchroom	Grand-cafe restaurant	Grand-cafe restaurant	Hotel	Boardgame store	Clothing store	Dairy shop
Shop locations:	Narrow street	Crossing	Crossing	Narrow street	Narrow street	Wide street	Wide street
Time working in shop:	15 years	14 years	4 years	34 years	6 years	16 years	4 years
Average time working in shop (in years):	13,29						
Age categories:	25-34 years (1)	35-44 years (1)	45-54 years (2)	55-64 years (2)	65+ years (1)		
M/F ratio	57,1% male, 42,9% female	4 male / 3 female					
Climate awareness:							
Awareness of climate issues in cities (/5,00)	3,57						
Which climate issues?	Absence of shade (6/7)	Heat radiation (3/7)	Air temperature (6/7)	Wind (2/4)	Relative humidity (1/4)		
Business affected by climate issues (/5,00)	4,00						
Awareness of solutions to climate issues in cities (5,00)	3,29						
Which solutions	Absence of shade (4/5)	Heat radiation (3/4)	Air temperature (5/5)	Wind (0/4)	Relative humidity (0/4)		
Design performance:	*Dealing with climate issues*	*Benefits my business*					
Wide street (/5,00)	4,86	4,29					
Narrow street (/5,00)	4,86	4,71					
Crossing (/5,00)	4,71	4,57					
Square (/5,00)	4,57	4,57					

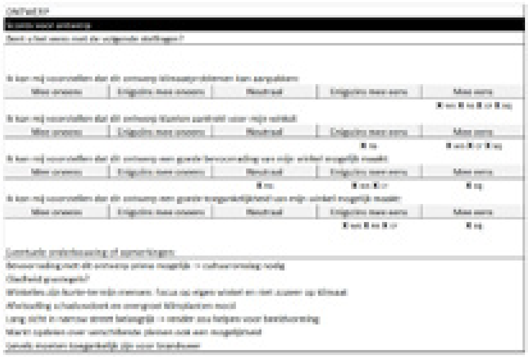
Interview outcomes session 1 - post-its

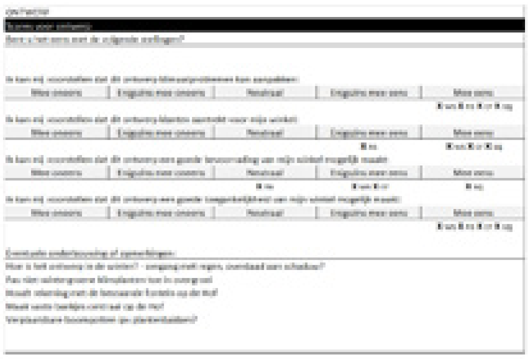
Interview outcomes session 2 - answers to interview questions and data analysis

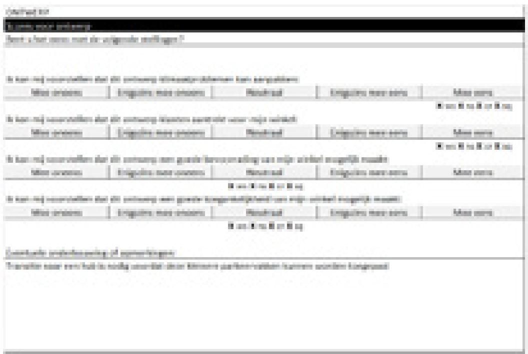


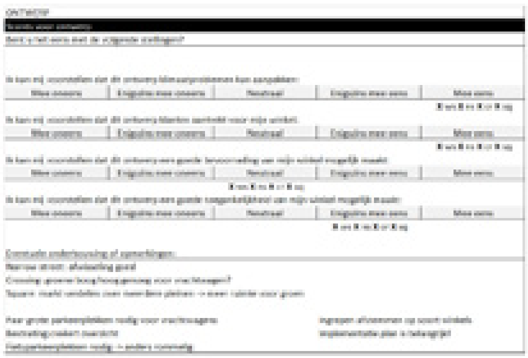












Design perfomance:	*Dealing with climate issues*	*Attracting clients*	*Possibility of inventory restock*	*Accessibility of shop*
Wide street (/5,00)	4,86	4,86	3,43	3,86
Narrow street (/5,00)	5,00	4,86	3,00	3,86
Crossing (/5,00)	4,86	5,00	3,43	3,86
Square (/5,00)	5,00	5,00	4,14	4,14

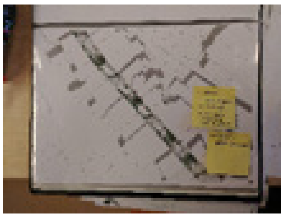
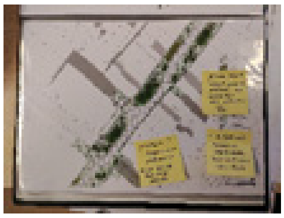
Interview outcomes session 2 - post-its









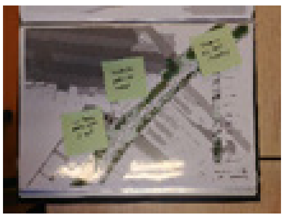














Interview number 6 in the second session was done within a limited time frame and workspace. Comments on the other three typologies were therefore written down in a notebook rather than on post-its.

Interview number 7 in the second session unfortunately had to be done online, rather than in a physical environment. Therefore, comments on all four typologies were written down in a notebook rather than on post-its.