Revitalising Urban Curaçao

A climate resilient plan for Wilhelminaplein in Punda



Delft University of Technology

TU Delft

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A climate resilient plan for Wilhelminaplein in Punda

by

Student Name	Student Number
Mauro van der Werf	4910141
Simon van der Windt	5102316
Abel Svejda	6095178
Joram Nottrot	4964551

Supervisor: Dr. Boris van Breukelen
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Faculty: Civil Engineering and Geosciences, Delft

Cover: Curaçao Activities [1]

TU Delft

Abstract

In order to **improve the climate resilience and liveability of Curaçao's Inner-City**, various interventions are proposed for Wilhelminaplein in Punda to mitigate the problem of heat stress, along with socioeconomic issues. This is done while keeping the problem of water scarcity in mind. Among various problem locations in the Inner-City, Wilhelminaplein was chosen as a development site because of its high potential and advantageous location. The main problems facing Wilhelminaplein are found to be extreme heat and lack of clear function, shade and maintenance.

Various possible solutions are proposed and discussed with experts, including a landscape architect and urban planner. Following this, the interventions are finalized and presented to various stakeholders, including representatives of relevant government agencies. Through a workshop, the stakeholders provided feedback on their preferred set of interventions.

The proposed interventions are subdivided into 'quick wins', cool spots and additional interventions. To quantify the effectiveness of the interventions, PET reductions of the proposed interventions are modelled using the modelling software RayMan. Along with the PET reduction, the initial cost, water usage, required level of maintenance and implementation time frame, are analysed for each proposed intervention.

To facilitate the practical implementation of the proposed interventions, an overview is given of which steps the relevant government agencies still need to take in terms of research, designs, and applying for permits.

Preface

Thank you for reading Revitalizing Urban Curaçao, a report focusing on enhancing climate resilience and liveability on Wilhelminaplein. It has been written to fulfil our multidisciplinary project course for the masters Environmental Engineering and Construction Management Engineering. For 10 weeks the four of us worked with great dedication and commitment as this topic is of great value for us. This acknowledgement section is intended to convey our appreciation to those who made this project possible.

We are deeply grateful to our TU Delft supervisors, Boris van Breukelen, Joris Timmermans, Arjan Droste, and Yirang Lim, whose expertise and insights guided each phase of this project.

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Finally we would like to thank all people who contributed to our project by contributing interviews, tours and being present during our final presentation and workshop. Your insights and opinions added essential perspectives to our project. The support we received has enriched our journey, making this project an unforgettable experience.

Mauro van der Werf & Joram Nottrot & Abel Svejda & Simon van der Windt
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Abbreviations

Abbreviation	Definition
Organisations	
APC	*NL*: Algemeen Pensioenfonds Curaçao
	EN: General Pension Fund Curaçao
BPD	*NL*: (Ministerie van) Bestuur, Planning en Dienstverlening
	EN: Ministry of Governance, Planning & Services
CTB	*EN*: Curaçao Tourist Board
DMO	*EN*: Downtown Management Organization
GMN	*NL*: (Ministerie van) Gezondheid, Milieu en Natuur
	EN: Ministry of Health, Environment & Nature
MEO	*NL*: Ministerie van Economische Ontwikkeling
	EN: Ministry of Economic Development
METEO	*EN*: Meteorological Department Curaçao
MFC	*EN*: Monument Fund Curaçao
OW	*NL*: (Uitvoeringsorganisatie) Openbare Werken
	EN: Public Works
ROP	*NL*: (Uitvoeringsorganisatie) Ruimtelijke Ordening en Planning
	EN: Department of Urban Planning
TU	*NL*: Technische Universiteit
	EN: University of Technology
UoC	*EN*: University of Curaçao
VVRP	*NL*: (Ministerie van) Verkeer, Vervoer en Ruimtelijke Planning
	EN: Ministry of Traffic, Transport & Urban Planning
Technical variables	
PET	Physiologically Equivalent Temperature
RH	Relative Humidity
T_a	Air Temperature
T_s	Surface Temperature
v	(Wind) velocity
VP	Vapour Pressure
Other	
ANG	*EN*: Antillean Guilder
BWV	*NL*: Bouw- en Woningverordening 1935
	EN: Building and Housing Regulations 1935
EOP	*NL*: Eilandelijk Ontwikkelingsplan
	EN: Island Development Plan Curaçao
SIDS	*EN*: Small Island Developing States
SDG	*EN*: Sustainable Development Goals

Chapter 1

Introduction

While climate change is a problem affecting every single country on earth, some countries are more at risk than others. For Small Island Developing States (SIDS) in particular, the climate crisis is the cause of extreme heat, extreme precipitation events and an increased risk of droughts [2]. This study aims to enhance the climate resilience of Curaçao, a Caribbean island belonging to the SIDS, particularly in mitigating heat stress, while keeping water scarcity in mind. This is done by combining the disciplines of environmental engineering - specifically the disciplines of atmospheric environmental engineering and water resources engineering - and construction management.

1.1. Overview of Curaçao, Willemstad and Punda

Curaçao is a small island in the southern Caribbean Sea, about 65 km north of Venezuela. Curaçao has a population of around 150,000 with an area of 444 km^2 [3]. It is an autonomous country within the Kingdom of the Netherlands. Before October 10, 2010, Curaçao was part of the Netherlands Antilles, a Caribbean federation of Dutch territories that included Bonaire, Sint Maarten, Saba, and Sint Eustatius [4]. Curaçao lies in the so-called Southern Caribbean Dry Zone and is characterized by a semi-arid to arid climate [5].

The local currency of the island is the Antillean Guilder (ANG), with an exchange rate fixed to the US Dollar at a price of USD 1 = ANG 1.80 [6]. The island has a GDP of around USD 4 billion (ANG 7.2 billion), which means USD 27,600 (ANG 49,700) per capita. The key sectors contributing to the island's GDP are tourism and financial services. In the past, oil refining and petrochemicals were also major contributors, but these were phased out in recent years. The GDP per capita of the island is relatively high compared to other islands in the Caribbean. Despite this, in a 2011 census by the CBS, the average yearly income was 36,276.00 ANG, and the median yearly income per person was 22,032.00 ANG. This indicates an unequal income distribution [7]. The same census found 25.1 % of people in Curaçao to live under the income poverty line.

The capital of Curaçao is Willemstad, of which the Inner-City is divided into four districts: Punda, Otrobanda, Pietermaai and Scharloo, see Figure 1.1. This Inner-City is a UNESCO World Heritage site [8]. The focus of this study, Punda, is the oldest of the four districts comprising the Inner-City.

Punda, the smallest of the four districts with an area of 0.14 km^2, can be considered the tourist heart of the island, consisting mainly of shops, restaurants and hotels. The area also includes some squares and monuments, with many buildings and streets being considered heritage sites. The iconic Handelskade is also located in Punda, see Figure 1.2. Partly due to rising housing prices and high maintenance costs, most inhabitants have moved out of the Inner-City, with Punda counting less than 50 people as of 2019 [9]. In recent years, the government of Curaçao has taken steps for people to move back into Punda [10].



Figure 1.1: Boundaries of the historic area of Willemstad and the main four districts [11]



Figure 1.2: The iconic Handelskade buildings in Punda, viewed from Emmabridge [12]

1.2. Objective and Strategy

Objective

The objective of this report is to provide an actionable plan for the Curaçao government, specifically the Ministry of Traffic, Transport and Urban Planning, to **improve the climate resilience and liveability of the Inner-City**. The project will focus on making the Inner-City a more attractive area during the day as, in the status quo, the Inner-City can become extremely hot and unattractive to walk through. This will be achieved with a concrete design proposal. The design proposal will be made at a location where heat and socioeconomic factors harm the living environment. A set of interventions will be sought that integrates solutions for the three focus criteria, being heat, water management and socioeconomic issues, and combines them into a single design.

Strategy

To complete the research objective, the project is broken down into five steps as illustrated in Figure 1.3. At the start of the project, the problem definition will be stated. Based on this problem statement, a clear project goal can be formulated. The different stakeholders and the relevant government organisation will also be analysed during this step to identify how such developments can be realised. After this, the development site that best fits the project goal will be determined. This site will be used throughout the rest of the project. This site will be determined by analysing existing data, own measurements on temperature and wind, and the report *Transforming Urban Curaçao* [9] (see Appendix A).

Additionally, the ideas of local inhabitants and relevant stakeholders will be inquired to find out what areas in the Inner-City they would like to see improved most. Once the development site is determined, the design process can commence. A set of interventions will be proposed based on reference projects, collaboration with the Ministry of Traffic, Transportation and Urban Planning, and different design iterations. Once the set of interventions is completed, the practicalities of the interventions will be mapped out in the form of cost overviews, impact, level of maintenance, and the concrete steps that are still needed for the intervention to be implemented. Lastly, to determine the project's success and impact on the city, evaluation methods will be presented on how the project's effects on the Inner-City can be quantified once interventions are implemented.

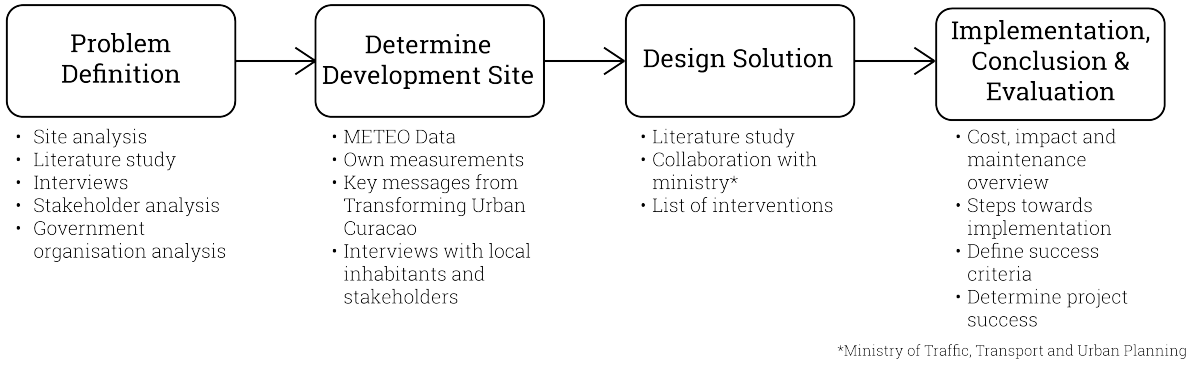


Figure 1.3: Research strategy

Chapter 2

Problem Definition

In this work, three main focus criteria are analysed, being heat stress, water management, and socioeconomic issues. Below is a breakdown of which problems Curaçao, specifically the Inner-City, faces with regard to these focus criteria.

2.1. Heat Stress

One of the biggest environmental issues in Curaçao is heat stress due to the hot climate and a limited amount of natural cooling features. In the neighbourhoods of Punda, Otrobanda, Scharloo and Pietermaai, there are hardly any well-shaded green parks; it is limited to some small-sized and not optimally maintained pocket parks, often encroached by parked cars. The urban centre is not suitable for walking as there is little to no protection from the sun. Historically, cars have been the main means of transport, even in the Inner-City. Creating shade on walkways and green areas is needed to reduce heat stress.

The urban heat is further induced by the high number of air-conditioning outlets on the streets. These outlets direct all excess heat from inside to outside. If the street canyons are not ventilated enough by the wind, the temperature on the street will increase. This may lead to a positive feedback cycle where even more air-conditioning is needed [13], see Figure 2.1. In extreme cases, temperatures may increase by 1-2.5 degrees, as shown in studies on Paris [14] and Tokyo [15].

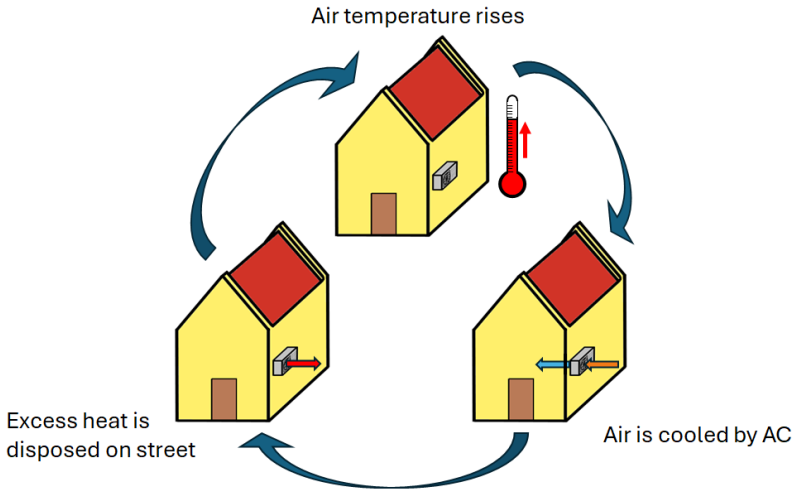


Figure 2.1: Feedback cycle air-conditioning on heat

In the past 120 years, temperatures have been increasing in Curaçao. In Figure 2.2, the temperature anomalies for measurements at Kas Chikitu and Hato stations are combined [16]. In the future, the temperatures will rise even more due to climate change. In Figure 2.3, the average temperature increase for the highest SSP (5-8.5) and lowest (SSP 1-2.6) KNMI climate scenarios are shown. These plots are for Bonaire, which is 50 km east of Curaçao. The plot shows the width of the temperature development under the different scenarios [17]. It must be noted that the average temperature could even increase

higher than 31.8 for 2100 as the 90 % confidence interval of the highest scenario lies between 30.8 and 32.8 [18]. It is extremely likely that there will be an increase in warmer and more frequent hot days and nights, warm spells and heat waves. The average maximum temperature for September, the warmest month of the year, is predicted to increase from 32.8 degrees in 2022 to 36 degrees in 2050 for scenario SSP(5-8.5) [19].

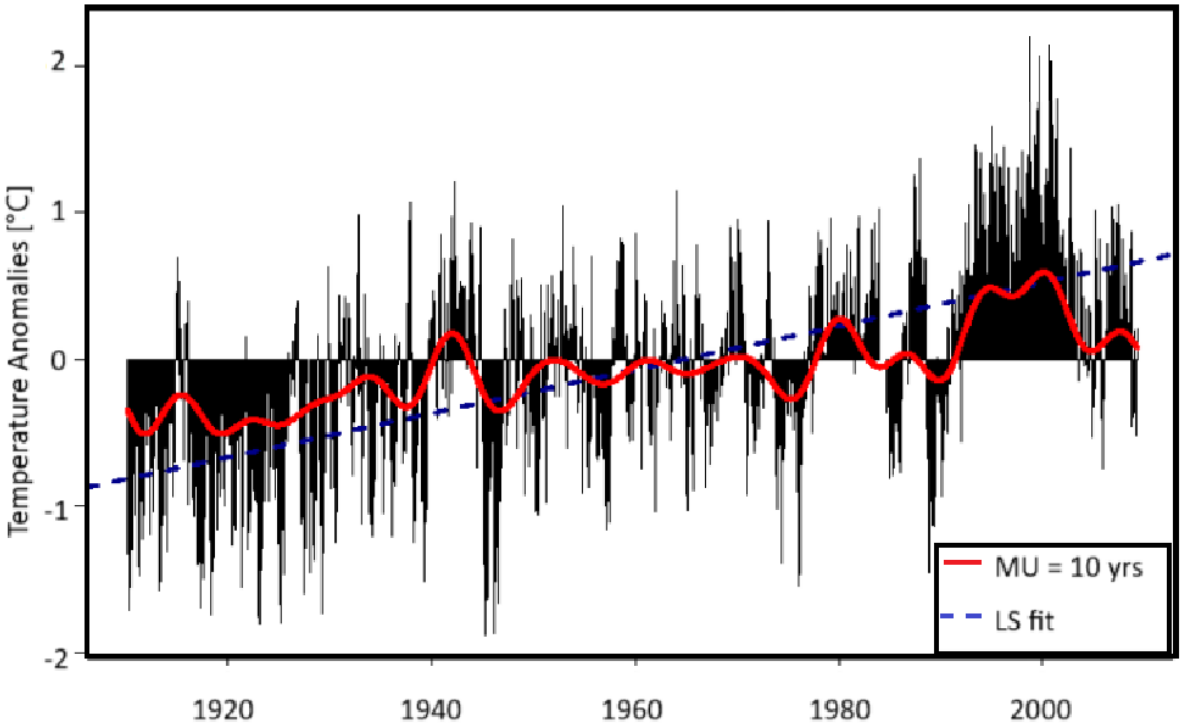


Figure 2.2: Temperature anomalies for the past 120 years for stations Kas Chikitu and Hato combined [16]

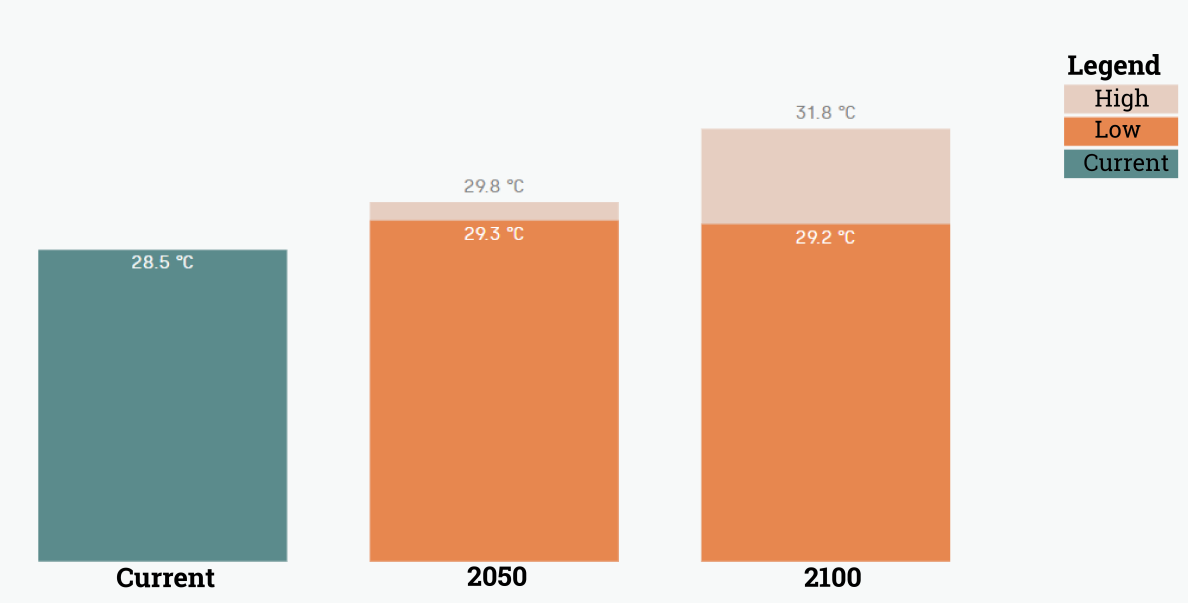


Figure 2.3: The predicted average temperature for KNMI climate scenarios for Bonaire. The current average temperature is the average for 1991-2020. The low scenario is based on SSP 1-2.6 and the high scenario on SSP 5-8.5 [17], [18]

The air temperature is not the only relevant variable for heat stress. The Physiologically Equivalent Temperature (PET) is more interesting because it better describes people's perception of temperature: thermal comfort. It is similar to perceived or apparent temperature. According to P. Höppe (1999), it is defined as the "air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed [20]. It takes into account the air temperature, wind speed, radiation, and relative humidity, see Figure 2.4. The 'typical indoor setting' is set to a wind speed of 0.1 m/s and a water vapour pressure of 12 hPa.

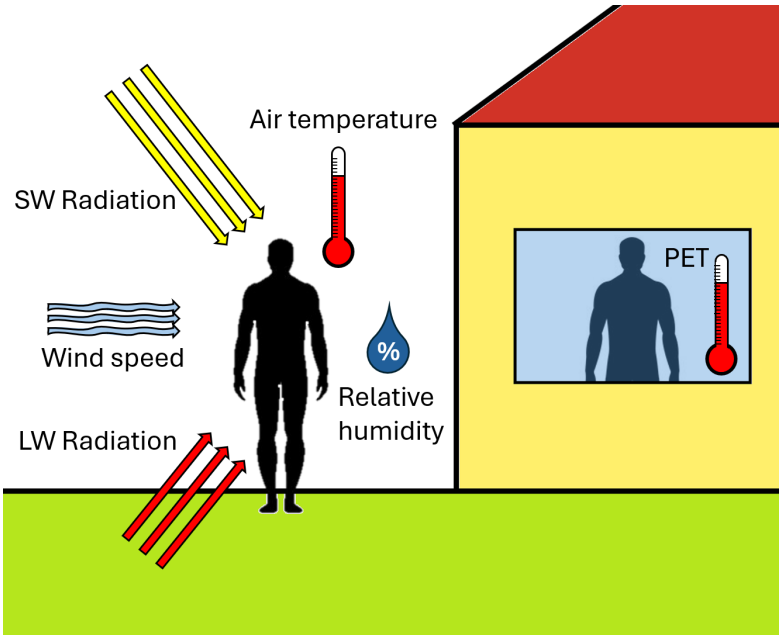


Figure 2.4: Two people experiencing the same heat stress. One person is experiencing multiple meteorological conditions, and one has just air temperature in a room and set variables.

The PET is defined in comfort scales from extreme cold stress to extreme heat stress. In Table E.1, the relevant comfort scales for this research are stated for a typical human being [21]. This is, however, for a European case. Various studies show that comfort temperatures in tropical regions lie much higher, with a neutral range up to around 30 °C [22] [23]. The higher comfort temperature can be explained by acclimatization, as people become physically and psychologically adapted to warmer conditions after prolonged exposure [24].

Table 2.1: Thermal Perception and Physical Stress by PET (°C) [21]

PET (°C)	Thermal Perception	Grade of Physical Stress
> 41	Very hot	Extreme heat stress
35 – 41	Hot	Strong heat stress
29 – 35	Warm	Moderate heat stress
23 – 29	Slightly warm	Slight heat stress
18 – 23	Comfortable	No thermal stress

Based on the Table and comfort temperatures from the literature, the thermal perceptions will likely shift 6-9 °C. It must be noted that this shifted perception can only be made for inhabitants of Curaçao and tourists from similar climates. This means that the following Table G.1 is assumed for drawing conclusions:

Climate change does not only influence the PET through air temperature, but also relative humidity and wind speed. Relative humidity has been decreasing slightly over the past 30 years [16]. An increase in average wind speed can be seen in the highest climate scenario of the KNMI for 2100 from 7.8 to 8.7 m/s; in the lowest scenario, the average wind speed does not change [17]. This, while the return period of hurricanes is not increasing in the highest scenario [18]. These two effects dampen the PET increase

Table 2.2: New Thermal Perception and Physical Stress by PET (°C)

PET (°C)	Thermal Perception	Grade of Physical Stress
> 50	Very hot	Extreme heat stress
$42 - 50$	Hot	Strong heat stress
$35 - 42$	Warm	Moderate heat stress
$30 - 35$	Slightly warm	Slight heat stress
$25 - 30$	Comfortable	No thermal stress

induced by increased temperatures. PET values are already in the strong to extreme heat stress for the Inner-City of Willemstad, so it is crucial to adapt the Inner-City to reduce the perceived temperature.

2.2. Water Management

Another environmental issue that Curaçao has to deal with is water management. The climate of Curaçao is defined as semi-arid to arid, with an average yearly precipitation of 550 mm [25]. Curaçao experiences a distinct wet season from October to December and a dry season from February through May. January, August and September can be considered transitional months [26].

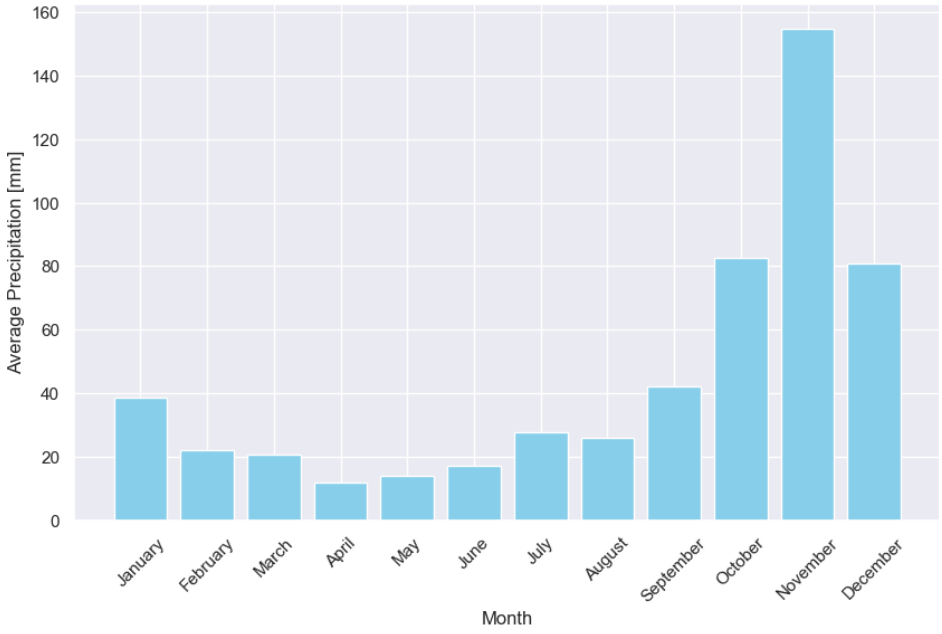


Figure 2.5: Average precipitation per month for each month, based on data from measuring station Hato from 2010 to 2024

Unlike many Caribbean islands, Curaçao lies outside (or rather on the southern fringe) of the hurricane belt. As such, the island is rarely threatened by hurricanes. However, extreme precipitation events do occasionally occur, often leading to flash floods [27]. Curaçao has natural dry river beds, called 'rooien,' which channel rainwater to the sea during extreme precipitation event. Despite this natural defence, flash floods are an increasing thread, especially in the western, rural part of the island [28]. Next to flash floods, a large part of Curaçao is also at risk from coastal flooding, with a 1-meter storm surge being capable of flooding various parts of the island (see Figure 2.6.)

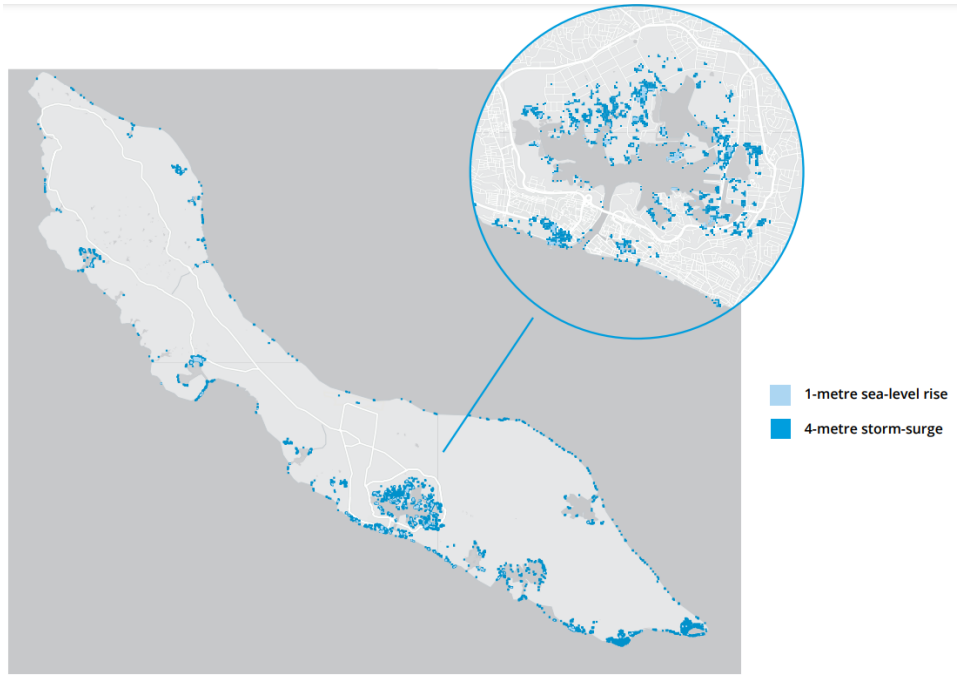


Figure 2.6: A map of Curaçao showing which areas are prone to coastal flooding for both a 1-meter and 4-meter storm surge [29]

Besides extreme precipitation events, Curaçao also experiences droughts, particularly during the dry season. These droughts are often exacerbated by the effects of El Niño and are expected to increase in intensity and frequency due to climate change [30], [31]. Figure 2.7 shows an estimation for the return periods of several drought durations in Curaçao, based on historical data obtained from METEO. Since the island does not have a reliable natural source of fresh water, having virtually no open water bodies, fresh water is deemed a valuable asset. Potable water on the island is largely provided by seawater reverse osmosis technology, which is expensive and energy-intensive [29]. Despite this, as of 2018, only 16 % of Curaçao's wastewater is properly treated, while the remaining 84 % goes untreated and is discharged into the terrestrial and marine environment [29]. This is due to a lack of treatment capacity. The current sewer infrastructure is also inadequate in many places, often overflowing during heavy rainfall [32]. The current water rate for domestic and commercial use is ANG 8.9/m^3 and ANG 14.4/m^3 respectively [33]. This means that water in Curaçao for domestic use is around 2.5 times more expensive than in the Netherlands [34].

In response to limited freshwater availability, the inhabitants of Curaçao have historically used various water retention methods. One such a method is building "dammen", small dams designed to slow down the water flowing through the *rooien* and direct it towards the surrounding soil. Due to water quality concerns, including an excess amount of nitrate, chloride and salt, the groundwater is typically not potable, limiting its use to irrigation purposes [35]. Residents have also historically implemented their own rainwater harvesting systems, through "regenbakken", a general term for cisterns or tanks used to catch water [36]. *Regenbakken* are still used by households today as a supplementary source of fresh water [37].

Despite the *dammen*, the fraction of precipitation that replenishes the groundwater is estimated at a maximum of 3.5 %, corresponding to 19 mm per year [25]. This is due to both the infrequency and intensity of precipitation events, which cause the soil to quickly saturate, as well as extensive surface sealing in the urban areas of Curaçao.

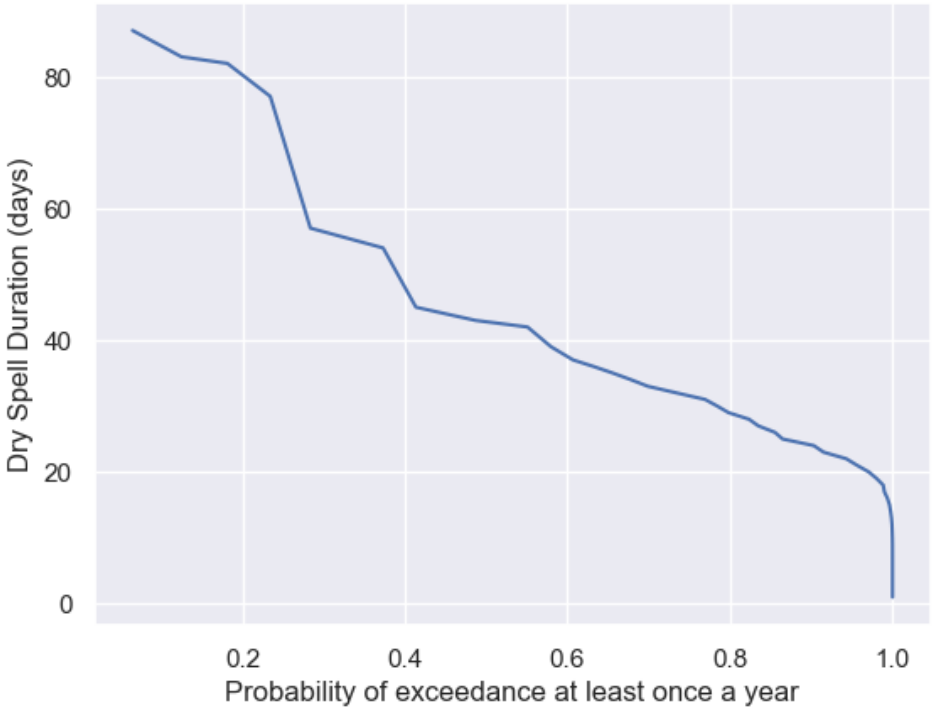


Figure 2.7: The return period of dry spells, based on precipitation data collected at Hato weather station between 2010 and 2024

Due to the inconsistency of rainwater and the high cost of treated water, water scarcity poses a significant challenge for Curaçao.

2.3. Socioeconomic Issues

Next to environmental problems, the Inner-City of Willemstad faces several socioeconomic problems. The three biggest problems are a decrease in the population living in the Inner-City, a high dependence on mobility by car, and a deterioration of the existing buildings and monuments due to a lack of maintenance.

The decrease in population started with the development of the Shell Oil Refinery and related harbour activities in Schottegat, Willemstad's safe and large natural inner-harbour, combined with the popularisation of the car [9]. When the city expanded to the suburbs, distances increased, and car dependency increased accordingly. Furthermore, roads are designed for cars, not for cycling or walking, and public transport is limited. These issues in the Inner-City are all interrelated and affect one another negatively. Increasingly more homes are being rented out to tourists, and a trend of people moving to sub-urban areas has decreased the number of inhabitants in the Inner-City. Due to high renovation costs, homeowners often deliberately neglect their homes to save costs [9]. The 2011 census also showed an above-average percentage of 'homes in bad condition' in the Inner-City [38], with Scharloo reaching 30.4 %, well above the 6 % island average. Between Punda and Pietermaai, there is an empty area that creates a barrier in the Inner-city.

Some alleys, such as Kuiperstraat and Windstraat, are abandoned and do not have a function anymore. They are used as illegal car parking and as places for the homeless to sleep. These streets are not used anymore as walking routes, see Figure 2.8. Wilhelminaplein is one of the most visited places in Curaçao, as the letters "CURACAO" and "DUSHI" can be found there. Furthermore, it is historically a place to meet. Every Thursday night, there is Punda Vibes, which creates a lively atmosphere in the square. The streets are also visually polluted by the abundance of air conditioners. Smaller streets and alleys are particularly susceptible.

This deterioration of homes, monuments and public spaces reduces the attractiveness of the Inner-City, which at the moment serves as one of the main tourist attractions. With the tourism industry being an important economic factor, this decline of the Inner-City has the potential to impact the

island's economy negatively.



a) AC outlets visually polluting a blocked alley

b) Cars parked along the Kuiperstraat

Figure 2.8: Examples of social problems in Punda

2.4. Conclusion

Three focus criteria are heat stress, water management and socioeconomic issues.

Heat stress is a major problem facing the Inner-City, with the liveability of various public spaces being threatened by extreme heat. This problem is expected to worsen in the future due to climate change. This study uses PET as a measure of human thermal comfort levels.

In terms of water management, Curaçao faces both flash flooding and coastal flooding, with the intensity varying spatially. A lack of reliable freshwater sources means that potable water in Curaçao is very expensive.

The Inner-City also faces several socioeconomic issues: a decrease in the number of people living in the Inner-City, a high dependence on mobility by car, and a deterioration of the existing buildings and monuments due to a lack of maintenance.

Improving the Inner-City on these three issues forms the aim of the project. By proposing concrete design interventions, improvements can be made. Not all of these issues are relevant in the Inner-City. For this reason, the areas that will be focussed on are mitigating heat stress, making sure water is used efficiently, and improving the quality of living in the Inner-City. This last area will help attract more people to live in this area.

Chapter 3

Stakeholder Analysis

Stakeholders are crucial for the realisation of a project. Therefore, it is important to have a good overview of the different parties involved in the whole process and the impact that they could have on the project. This chapter takes a closer look at the relevant stakeholders and their importance.

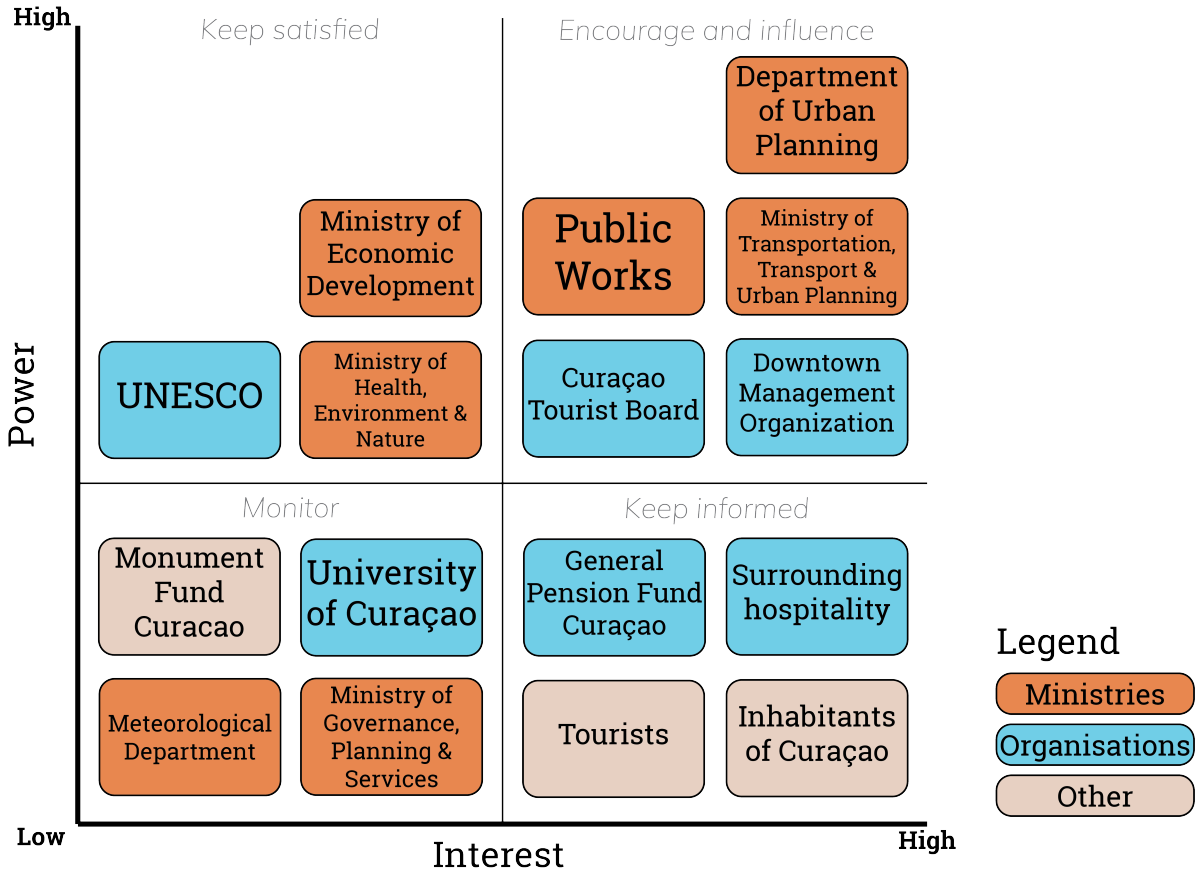


Figure 3.1: Stakeholder Power-Interest grid

In Figure 3.1 an overview of the different stakeholders is shown, categorised by their levels of power and influence on the project. Each stakeholder is managed based on where they are located in the figure. The bottom-left sector consists of stakeholders that have little power and interest. Stakeholders in this sector primarily provide assistance and data. Monitoring these stakeholders and maintaining a positive relationship is important in ensuring the project is executed properly.

The bottom-right sector consists of the stakeholders who are highly interested in the development but do not have much decision-making power. It is good to keep these stakeholders informed as they mostly consist of the end-users of the development.

The top-left sector comprises stakeholders with significant power but limited involvement in the project. These stakeholders should be kept satisfied. These stakeholders will not interact much with the project unless the development goes against their interests. This could shift them from the top-left to the top-right sector, making them a greater threat to the project.

In the top-right sector, the stakeholders with the highest interest and the highest power are placed. These are the stakeholders that should be managed closely. As long as they are positive about the development, they are strong allies, but once they don't align with the plans, they can become a threat to the project.

3.1. Stakeholder Overview

Ministry of Transportation, Transport & Urban Planning (VVRP)

VVRP is the ministry responsible for developing and monitoring the urban landscape of Curaçao. They aim to do this in a whole, safe and clean way [39]. Next to this, they are responsible for ensuring good (inter)national connections, protecting society against dangerous weather events, and optimising land use by adequately arranging infrastructure and housing opportunities. The ministry consists of several departments, each responsible for a specific task. These specific departments, such as the Department of Urban Planning, Public Works, and the Meteorological Department, are responsible for the actual implementation of the policies the ministry describes. Moreover, VVRP will be involved in the design and implementation processes. Therefore, VVRP is classified in the high-power, high-interest sector.

Department of Urban Planning (ROP)

ROP, the implementation department of VVRP, ensures balanced and sustainable land use on Curaçao [40]. Building permits are approved or denied based on the ministry's policy to ensure they meet the required standards. In this way, they are responsible for green lighting the design and the implementation of public spaces in Curaçao. These decisions are based on the Island Development Plan (Eilandelijk Ontwikkelingsplan, EOP). The EOP contains the general vision for the island and what values should be kept in mind during development. The specific parts of the EOP relevant to this case are shown in Appendix I.1. ROP's power to accept and deny permits and their responsibility for Curaçao's public spaces place them in the high-power, high-interest sector.

Public Works (OW)

OW is another sub-organisation of the VVRP. They are responsible for building and maintaining all physical infrastructure, public facilities, public spaces, and greenery [41]. For this case, OW's biggest impact lies in the implementation of the interventions. Consulting them about the possibilities and feasibility of the interventions is important for the step towards implementation. They are limited by their own budget restraints. This means that they have the power to decide what interventions would be possible and feasible. This places them in the high-power, high-interest sector.

Meteorological Department (METEO)

METEO is another department responsible for one of the tasks of VVRP. They collect and document all meteorological data on the island. This data library will be extremely helpful for the project, as it makes it possible to run simulations of possible weather scenarios and calculate the heat stress in the city. METEO themselves have no direct interest or power in the development of Punda. Therefore, they are placed in the low-power, low-interest sector.

Ministry of Health, Environment & Nature (GMN)

GMN is the ministry responsible for the healthcare, veterinary affairs, nature preservation and agricultural and fishing industry on the island [42]. Most relevant to this project is MNB, the Department for Environment and Nature Preservation. This department is responsible for the upkeep of the nature of the island. This includes taking care of the greenery in the Inner-City. This task overlaps with OW's responsibilities of maintaining public space and greenery. This grey area of responsibility has often led to ambiguities and disagreements regarding who is responsible for which maintenance task. Still, without their cooperation, the proposed greenery would likely not persevere due to a lack of irrigation and maintenance. For this reason, GMN is an important stakeholder that has the power to make the project unsuccessful. GMN is placed in the high-power, low-interest sector.

Ministry of Governance, Planning & Services (BPD)

BPD is the ministry responsible for the proper functioning of the government and the democracy. They do this by constructing and maintaining a masterplan for Curaçao, ensuring information is available for the citizens and government, and optimising government processes [43]. They are also responsible for giving out certain permits, and they are the ministry where citizens can inquire about the decision-making process behind permit applications and other governmental decisions. The Central Bureau of Statistics and the National Archive also fall under BPD. For this project, their relevance lies mostly in providing information; therefore, they are placed in the low-power, low-interest sector.

Ministry of Economic Development (MEO)

MEO is the ministry responsible for the sustainable economic development of Curaçao. Their goal is to increase the prosperity of the entire island and help it become a strong and competitive economy [44]. Their power lies in the fact that they can decide how and where governmental funds are spent. Their budget to improve the economic state of Curaçao could be an important factor in the development of Punda, but they are not involved in the urban planning processes. Therefore, they are placed in the high-power, low-interest sector.

Downtown Management Organization (DMO)

DMO is the interest group that represents the retailers and entrepreneurs of Punda. They have a large interest in the liveability of Punda as their revenue is mainly based on the people visiting the Inner-City. As they represent all owners, they also have an important voice in discussions about the area. This makes them a high-power, high-interest stakeholder. Recently, they have consulted an urban planner to present a plan for the future of Punda called "The world of Punda" [45]. In this plan, presented in May 2024, Hans van Aalst presents his vision for the development and management of Punda. These developments are aimed to be executed in the following years.

Curaçao Tourist Board (CTB)

CTB is a non-profit organisation with the goal of promoting Curaçao as a tourist destination. Their main tasks are marketing the island as a prime tourist destination, proposing and supporting initiatives that improve the tourist experience, forming an advising body on tourism policies for the government, and tracking relevant data regarding the tourism industry [46]. Their main funding comes in the form of subsidies by MEO. They work closely with the ministry and have a high level of influence on the decision-making within their specific expertise. They were also the main initiator behind the development of the Marie Pampoen area, which is being regarded as a successful project by tourists and local inhabitants [47]. CTB is placed in the high-power, high-interest sector due to its close connections with the government and its direct interest in improving the tourist experience.

General Pension Fund Curaçao (APC)

APC is responsible for the pensions of around 22,000 Curaçaoans. Part of their profits come from investing in real estate. They are relevant to this project as they are currently responsible for the development of the former Plaza Hotel. This monumental building in Punda will be torn down and replaced by a new construction project. The new building will combine housing with amenities and working spaces [48]. This will boost the number of inhabitants living in Punda, affecting how the Inner-City will be used. Additionally, APC should be consulted as it is also to their benefit to create a liveable public space for the future buyers of the apartments. This places them in the low-power, high-interest sector.

UNESCO

UNESCO is another relevant stakeholder in the project. The historical Inner-City and port area are inscribed in the UNESCO World Heritage List [49]. This means that the government of Curaçao is responsible for maintaining the Historical value of the Inner-City. Otherwise, they risk losing their UNESCO Heritage status. This status is important for the city of Willemstad as it helps attract tourists. Therefore, when developing in the Inner-City, it is important to maintain the historical value. UNESCO does not have much interest in the development of Willemstad as long as it does not violate the guidelines they set. If it goes against their wishes, they can disrupt the project by threatening to remove the UNESCO Heritage status. For this reason, they are placed in the high-power, low-interest sector.

Monument Fund Curaçao (MFC)

MFC is a fund for the restoration of monumental buildings in Curaçao. By giving out loans and subsidies to organisations and individuals on behalf of the government, they support the maintenance of the island's historical buildings [50]. They are not directly involved in the redevelopment of the Inner-City but could help with the funding if monumental buildings are included in the project. Therefore, they are placed in the low-power, low-interest sector.

University of Curaçao (UoC)

UoC is a small stakeholder in this project. As the biggest higher education facility on the island, it benefits from a more climate-resilient Punda. It is able to provide information in the form of conducted research into the topic. They can also provide measuring equipment and possible networking opportunities to other stakeholders. The UoC can support the project, but is not much affected by the outcome. Therefore, they are placed in the low-power, low-interest category.

Inhabitants of Curaçao

One of the stakeholders with possibly the most interest in the project are the inhabitants of Curaçao. As written in the problem description, many inhabitants that used to live in Punda have moved to the suburbs in the last decades. This leaves the streets empty during most parts of the day or only filled with tourists. Many residents remember Punda as a thriving downtown where they enjoyed staying [51]. These times are in the past, but it is not impossible for them to return. The correct developments could bring life back into the Inner-City. The inhabitants themselves do not have much direct say in the decisions being made. Therefore, they are placed in the low-power, high-interest sector.

Tourists

Tourists are responsible for an important amount of the revenue of Curaçao. Currently, an estimated 70 % of all stay-over tourists visit the city centre [9]. It is, therefore, well in their interest to reduce the heat stress in the Inner-City. Their only form of influence on the developments and decision-making comes in the form of their consumer behaviour. Therefore, they are placed in the low-power, high-interest sector.

Surrounding hospitality

Punda houses a large group of hotels, restaurants, and cafes, all of which heavily rely on the visiting tourists. The number of tourists that will visit Punda and the time they will visit are positively related to a more liveable area. Therefore, they are also indirectly impacted by the development. They have some influence through DMO, but for individual owners, this is limited. For this reason, they are placed in the low-power, high-interest sector.

Stakeholder Management

After the stakeholders are divided in a Power-Interest grid, it is important to determine how to interact with each stakeholder during the project. Figure 3.2 shows how close each of the stakeholders will be interacted with. Important to note is that this Figure is made from the perspective of this project so it might not be applicable to every similar project. The project itself is located in the middle circle, and the different circles around it indicate how much cooperation is expected from each stakeholder.

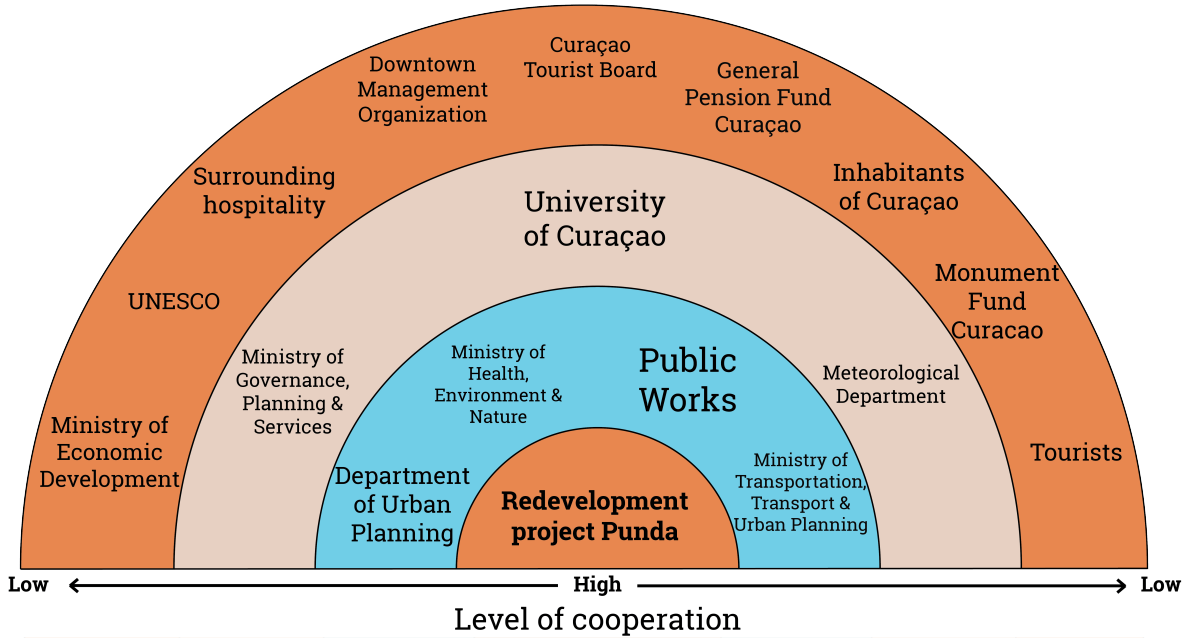


Figure 3.2: Level of cooperation model

The first circle consists of the stakeholders that are highly important to the project. These stakeholders have much influence on the project's outcome, making their cooperation crucial. These stakeholders should be kept in close contact during the entire design process to ensure their wants, needs and demands for the development. Because of their high influence, they can thwart the development if it does not align with their vision of the area.

The next circle consists of the stakeholders who do not have much influence on the project's outcome but can provide the project with relevant data and resources. The connections with these stakeholders should be maintained well, as they are essential to a successful project outcome.

The outer circle consists of the stakeholders who will not be cooperated with intensely. It is important to research their opinions and desires as they will be affected by the outcome and could influence the process if they would want to.

In conclusion, stakeholder engagement should be based on their level of influence and interest in the project. This customisation helps to ensure efficient communication and increases the project's chances of success.

3.2. Organisation Structure Analysis

Next to having clear what stakeholders are involved and affected by the project, it is important to know the organisational structure responsible for the decision-making and implementation process. Knowing which parties are responsible for what will help determine who to contact and collaborate with for every part of the process. Based on this, meetings with the relevant parties can be planned. This section will give an overview of all responsible parties and their exact area of responsibility.

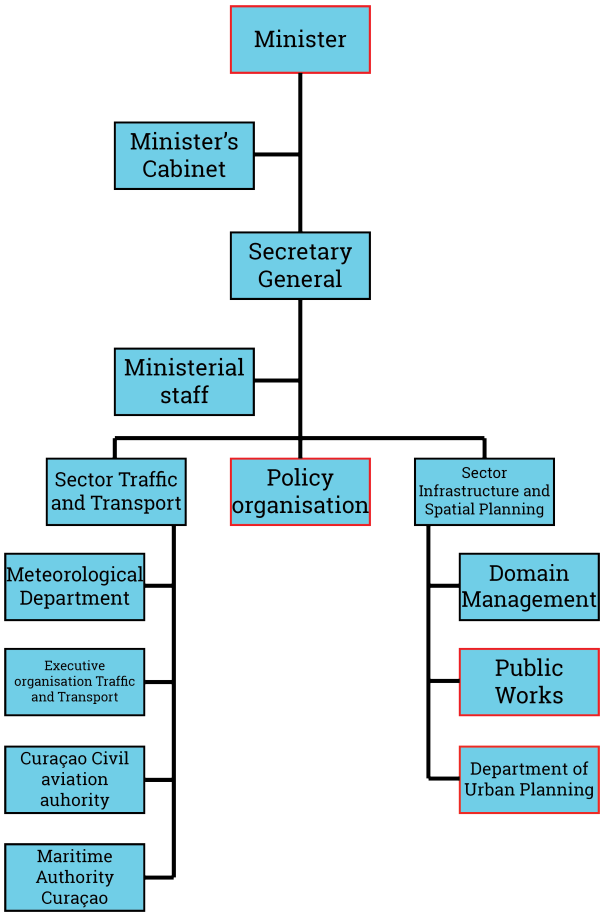


Figure 3.3: Organisation structure of the Ministry of Transportation, Transport & Urban Planning (VVRP) [52]

Figure 3.3 shows the organisation structure of VVRP. Within VVRP, parties relevant to the project's approval and implementation are marked in red. The Policy Organisation initiates development plans. ROP then checks these plans to see if they comply with the EOP. This ensures the plans align with the overall vision for the island. OW is then responsible for the execution and maintenance of these plans. Additionally, if the plans consist of greenery, GMN should be consulted about the maintenance.

In theory, all these institutions could work independently of each other if they only fulfil these roles. In practice, it is not as easy. The Policy Organisation of VVRP does not have the authority to independently decide what should be developed; ROP and OW also have their own visions for which developments should be implemented, and they both have enough power to enforce these. Additionally, before development can commence, an agreement about the maintenance will have to be made by OW and GMN regarding the greenery. To ensure successful implementation, a cooperative agreement between the four parties involved is beneficial. Once this agreement has been made, the specifics towards implementation can be finalised. The goal of this project is to achieve this cooperation agreement. The finalising of the details is beyond the scope of this project, but by proposing interventions that all parties agree on, the start of the development process will be initiated.

Chapter 4

Determine Development Site

This chapter aims to identify the area within the Inner-City that will be prioritized for redevelopment. This decision will be based on several analyses. First, the existing visions for the Inner-City will be analyzed from documents and interviews. These analysis highlights the key weaknesses and opportunities within the Inner-City. Subsequently, temperature and wind speed measurements will be taken at specific locations within the Inner-City. Combined with meteorological data, this will be used to determine which areas of the Inner-City are most in need for heat stress mitigation. Based on these analyses, the area where development would have the most impact will be chosen. In the following chapters, the design for the chosen development site will be described, and its effect will be highlighted.

4.1. Transforming Urban Curaçao

The three sections below are based on Chapters 3, 4 and 5 from the UNOPS report *Transforming Urban Curaçao*, respectively. This report summarizes the process and results of the adaptation of the New Urban Agenda to the local context in Curaçao. The results give some clear indications to the Government of Curaçao on what could be its future spatial planning initiatives, supporting the development of resilient infrastructure on the island and generating social and economic progress [9]. They are to summarize some of the key findings from each chapter. A more detailed overview can be found in Appendix A.

Focus Areas

The report describes several focus areas in the cities of Barber, Montaña and Willemstad. Five of them are located in Punda. For example, the various empty hotel buildings, like the Plaza Hotel building. The Kuiperstraat is also mentioned, which has lost its historic character and liveability. Many alleys in the Inner-City have been blocked by fences or gates and they are often visually polluted by air-conditioning outlets. Lastly, modern functional buildings that do not blend in disrupt the character of the historic Inner-City.

Community-based Vision

The report includes both a community-based vision and an expert-based vision. The relevant community ambitions for Punda are to bring people together, preserve nostalgic memories and create open public spaces.

The community wants the city to be people-oriented, accessible to anyone, and more inclusive. The distribution of jobs, opportunities and services should be fair. To achieve this, objectives for 2030 have been formulated. The objectives most relevant to this project are summarized below.

- Making the city-centre vibrant, economically thriving, and sustainable
- Making Willemstad a city in which the local people are central, where residents are involved in the decision-making and everyone has a sense of place
- Making Willemstad a city that is climate-proof, with well-maintained buildings and sustainable water management.

Expert-based Vision

The expert team consisted of three international and four local independent urban planners. The experts share partly the same vision as the community. In addition, they have a number of technical requirements, including controlling the decline of the population, improving accessibility and making the city more sustainable and resilient.

The vision also discusses the presence of both physical and psychological barriers, limiting people's movement throughout the city. The physical barriers refer to gated or blocked alleys. Psychological barriers are busy roads or unpleasant areas that pedestrians prefer not to cross. The experts want Punda to become the beating heart of the city again. Therefore, the Inner-City must be a pedestrian experience that is easily accessible from outside. The walking experience must be improved through shading, green areas, protection from UHI, and scenery.

The vision also proposed reconfiguring the Plasa Wilson 'Papa' Godett, creating pocket parks in smaller areas like the Kuiperstraat, and reopening closed alleys.

Focus Areas

Figure 4.1 highlights the five focus areas.



Figure 4.1: Five possible focus areas within Punda, marked with corresponding colours [53]

4.2. Interviews

Interviews have been conducted with representatives from the Ministry of VVRP and DMO. This includes Pédzi Girigori, senior policy advisor for VVRP and chief operations officer at METEO, Caroline Gonzalez-Manuel, sector director for the Ministry of VVRP and Michelle Metsch, chairwoman of DMO. As part of Curaçao's 2030 sustainable development goals (SDG), VVRP has also organised an SDG Tour on September 20th 2024. During the tour, several focus areas inside Punda were explored, and opinions on the problems and opportunities for said areas were collected from representatives of VVRP and DMO. The primary focus of this part of the tour were Wilhelminaplein and the Kuiperstraat.

Wilhelminaplein

Wilhelminaplein is cited as a key area for potential redevelopment [10]. The square used to be a vibrant green park, with people holding various fond memories of it. After a development in 2009, most of the green was replaced by concrete, leaving only some trees and a small patch of grass. In recent years, due to the inactivity of the square, irrigation of the grass patch and the functioning of the fountain in the centre have stopped in an effort to save water.

During the SDG tour, Pédzi cited a major issue of Wilhelminaplein to be a lack of attractiveness. Major factors contributing to this problem are a lack of identity, a lack of shade and disturbances from cars [10].

According to Caroline, the square has been designed to be able to accommodate several functions, including an event location, a tourist attraction site and a recreational area. As a result of these multiple design functions, the square excels at none of them and would benefit from having one clearly defined function [54].

Caroline, expressing the need for shade and cooling for visitors of the square, discussed the possibility and limitations of the implementation of trees. While trees have a very clear function in cooling, it should be kept in mind that trees need a lot of water and can obstruct visibility. Michelle has cited the Ministry of Health, Environment and Nature (GMN) as an important stakeholder considering the planting and maintenance of trees [55].

Both Pédzi and Caroline have expressed the wish to limit the number of cars that drive around the square to minimise the disturbance in noise and reduce their negative impact on mobility [10] [54]. The traffic around the square is partly due to the parking spaces surrounding it from both the eastern and western sides. According to Caroline, the car park on the west side in front of the Ministry of Justice and City Hall cannot be moved as people who work at these organisations want to continue to park here. It may be possible to create a gate so that only employees of surrounding buildings can park there, thus reducing the number of cars on the street towards that car park. Due to contracts with the parking management organization, removing the car park on the east side is also difficult, as another parking area would need to be designated, and there are currently no plans to do so, partly because there are no spots available on such a central location.

Kuiperstraat

The primary issue affecting Kuiperstraat is its diminished liveability. Once a lively historic street, it is now mostly abandoned, with only a single household still living in the street [10], a clear example of the exodus from the Inner-City as underlined in *Transforming Urban Curaçao* [9]. Due to the lack of maintenance of the abandoned buildings and the numerous air-conditioning units cluttering the walls, the street has a very unwelcoming appearance. Pédzi notes that a major problem in terms of appearance and mobility is the high number of cars parked in the street. While parking on the street is not allowed, the lack of enforcement has led to people using it as a makeshift parking area. In an interview with Michelle, the Kuiperstraat is mentioned as ”a quick and easy win” in the sense that improvements can be made with relatively little investment [55]. DMO’s vision for the Kuiperstraat includes turning it into a bar street, where people gather to relax, socialize and drink, especially in the evenings [56]. To further facilitate this vision, Michelle has added the wish to implement a herbal garden throughout the street.

Student Survey UoC

Another important stakeholder group that was consulted were the inhabitants of Curaçao. This was done in the form of a survey filled out by students of the University of Curaçao. This group is not representative of the entire population of Curaçao, but it does give insight into how people view and use Punda. An overview of the survey and the responses can be found in Appendix G.1. The most important conclusion was that the students valued the history and atmosphere of Punda, but they liked to see improvements in the form of better hygiene and maintenance of the buildings. They would also like to see more events being held in Punda, as this was one of their main reasons for visiting. Lastly, the majority of students responded that they would visit Punda more often if it had more cool spots.

4.3. Temperature Analysis

For the temperature analysis, various places were investigated. Surface temperatures are measured once with the EXTECH 42509 IR Thermometer with Color Alert [57]. Air temperature and wind speed were measured with the EXTECH 45170CM [58]. There was one of both instruments available. The 5-minute measurements for wind and air temperature were manually taken at 10-second intervals as the device does not have data recording or storage capabilities. This also means that longer and more frequent measurements were not practical. This method is susceptible to errors, especially because wind speed and air temperature varied greatly during the measurement time. The temperature measurements were corrected for diurnal variation with the METEO station in Punda. Therefore, these measurements were conducted to gain general insights rather than to draw scientific conclusions.

The measurements were used for calculations in RayMan, an Urban Climatology Model, to determine PET. More information on the functioning of this model can be found in Appendices C and E. Measurements were taken strategically: multiple measurements were taken on different days to account for errors related to the time of day. Additionally, the effects of different attributes were investigated. This includes the impact of air-conditioning outlets in de Windstraat and that of a crochet canopy. For all locations, a fish-eye photo was taken to input as the sky-view factor in the RayMan model. These pictures were modified to make it easier to distinguish between sky-view, buildings and trees. They were taken in North direction and stored as a *.bmp*-file. An example is given in Figure 4.5.

For use in RayMan, the temperature measurements were corrected for diurnal variation. The PET values are corrected to the time period 12:30-15:30, which are the three hours of the day in Curaçao with the highest air temperature. The wind speed measurements are used. Relative humidity and cloud coverage are other necessary inputs, which are gathered from the METEO station in Punda. The percentage of vegetation around the measuring point is used to calculate the Bowen ratio. This Bowen ratio determines the ratio between sensible and latent heat by evaporation. Lastly, the personal data and clothing of an average inhabitant of Curaçao are used. Detailed descriptions for the measurement method can be found in Appendix B and the results of the measurements can be found in Appendix D. In Figure 4.3, all measurement locations used in Punda are shown. More information about the inputs and calculation technique of the PET can be found in Appendix C. The results the PET calculation can be found in Appendix E.



a) Locations of the Sebastopolstraat and the Rifwaterstraat



b) Crochet canopy in the Sebastopolstraat

Figure 4.2: Streets in Otrobanda



Figure 4.3: Map of measurement locations in Punda

To see the effect of a crochet canopy, the air temperatures and PET values in the Sebastopolstraat (Otrobanda, Fig 4.2) were compared to those of the Rifwaterstraat, 85 meters down the street. The difference in air temperature is 0.8°C, as the Rifwaterstraat had an air temperature of 35.5°C and the Sebastopolstraat of 34.7°C. Noteworthy, the Sebastopolstraat was measured to be warmer in the morning but cooler in the afternoon. This indicates that the crocheted canopy is also able to hold heat. On average, however, the canopy will reduce temperatures on the street, and it especially mitigates extreme temperatures. The decrease of the PET is 7.2°C, as the Rifwaterstraat had a PET of 54.6°C and the Sebastopolstraat of 47.4°C. This difference is mainly due to the shading provided by the crochet canopy.

In Figure 4.4, the PET is shown for each measurement location, with exact values detailed in Table 4.1. It is evident from the Figure that all measurements fall within the strong or extreme heat stress categories. This is expected since these PET values are calculated during the hottest part of the day in the hottest month of the year. Focusing on the hottest time of day reveals areas that exhibit the most extreme cases of heat stress.

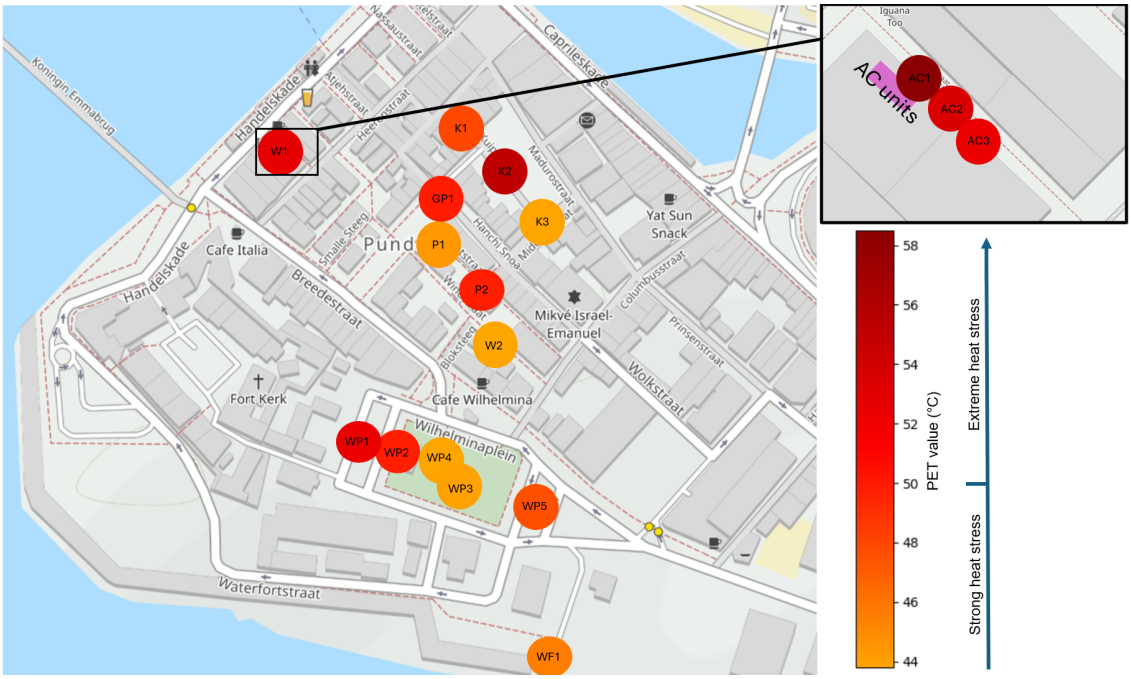


Figure 4.4: Results for the PET calculation per measurement location in Punda. The ID is shown per location and is used in Table 4.1 for the exact PET and location. The zoomed part is the PET measurement for our experiment with the air-conditioning units. There were 5 active air-conditioning units. The first measurement was at 1 m, the second at 4 m and the third at 8 m.

Table 4.1: Air temperature (Ta), wind speed (v), PET, and location for each measurement point

ID	Location	Lat (°N)	Lon (°E)	T_a (°C)	v (m/s)	PET (°C)
GP1	Da Costa Gomezplein	12.105546	-68.933452	34.9	0.36	49.8
K1	Kuiperstraat	12.105905	-68.933289	34.4	1.6	48.0
K2	Kuiperstraat	12.105821	-68.933174	34.6	0.46	55.2
K3	Kuiperstraat	12.105497	-68.932918	33.7	2.9	43.8
P1	Passaatstraat	12.105386	-68.933460	33.6	2.4	44.4
P2	Passaatstraat	12.105172	-68.933234	34.0	0.90	49.8
WF1	Waterfordstraat	12.103156	-68.932912	32.4	1.5	45.6
WP1	Wilhelminaplein	12.104406	-68.933785	35.7	0.73	52.4
WP2	Wilhelminaplein	12.104282	-68.933646	35.3	0.45	49.8
WP3	Wilhelminaplein	12.104192	-68.933380	32.9	2.0	44.0
WP4	Wilhelminaplein	12.104239	-68.933412	33.0	1.5	43.8
WP5	Wilhelminaplein	12.104042	-68.933028	34.0	1.3	47.6
W1	Windstraat	12.104873	-68.933191	35.1	0.67	52.7
W2	Windstraat	12.104873	-68.933191	33.3	2.7	43.8
WAC1	Windstraat	12.105861	-68.934232	35.8	0.38	58.5
WAC2	Windstraat	12.105862	-68.934233	35.0	0.68	53.5
WAC3	Windstraat	12.105863	-68.934234	34.4	0.74	52.4



a) Fish-eye picture of the crossing between the Passaatstraat and the Middenstraat

b) .bmp file input into RayMan model

Figure 4.5: Example (Passaatstraat 2) of the skyview factor input into the RayMan model

The PET values from Figure 4.4 are difficult to use for conclusions due to significant fluctuations in variables like wind speed and air temperature during measurements. An increase in wind speed lowers the PET substantially, leading to a large variability in the results. An example is the difference between K1 and K2, which is the result of the difference in wind speed as K1 has an average windspeed of 1.6 m/s and K2 has an average wind speed of 0.46 m/s. As these two measurements are in the same street canyon, they are largely defined by the variability of wind gusts.

It can be seen that the parking areas around Wilhelminaplein (WP1 & WP5) exhibit high PET values. On Wilhelminaplein, the PET difference between WP3 (in the square centre) and WP4 (under a shaded tree) is minimal, as lower wind speeds for WP4 damped the shading effect on PET. This variability suggests the data's limitations for comparing different streets, emphasizing that longer measurements at multiple locations at the same time are needed. Therefore, this data is only used for

general insight into the effect on the PET.



Figure 4.6: Air-conditioning units in the Windstraat

The air-conditioning data in Table 4.1 and Figure 4.4 shows that both air temperature and PET (Physiological Equivalent Temperature) increase significantly near the units, reaching a peak PET of 58.5°C at one-meter distance. Figure 4.6 shows a picture of the air-conditioning units; five units were active at the measurement time. In high-wind conditions, increased air mixing reduces the local temperature effect of the units. Conversely, this mixing is limited in low-wind conditions, causing a more pronounced heat accumulation at street level [59]. Positioning air-conditioning units on rooftops rather than at street level could mitigate this localized heat effect and benefit the street's attractiveness.

The PET values for all locations are in the strong to extreme heat stress category. Therefore all locations could be improved. The residence time is also important as people only use the Kuiperstraat, Windstraat and Passaat mostly for walking. Wilhelminaplein and Da Costa Gomezplein people tend to stay longer as there are restaurants and tourist attractions such as the DUSHI and CURACAO letters on Wilhelminaplein.

4.4. Impact

The areas most named in the interviews are Kuiperstraat and Wilhelminaplein. For the Kuiperstraat, a plan is already made by DMO [56]. It is preferred to make the Kuiperstaat a cosy barstreet, where you can enjoy a beer until late in the evening. This street comes to life after 5.00 pm through the location and in collaboration with the food trucks on the Jo-Jo Correa and the connection with the Keukenstraat. The Keukenstraat is well-used in the evening hours. The different streets are shown in Figure 4.1.

The impact of this project on the Kuiperstraat would be lower than on Wilhelminaplein. No plans have been made for Wilhelminaplein yet. There is only the wish to make the Breedestraat car-free [56]. Many measures can be taken at Wilhelminaplein to create a more climate-adaptive location. In the Kuiperstraat, only a few measures can be introduced to lower the impact. The most important measure in the Kuiperstraat is turning the buildings into bars.

4.5. Conclusion

Transforming Urban Curaçao was used as the starting point of this project. The site determination process is, therefore, limited to the five focus areas highlighted in Chapter 4.1. From there, through interviews with different stakeholders and excursions through Punda, the problems and potential of each of the focus areas became clearer and clearer. By conducting temperature and wind measurements throughout Punda, it was possible to determine how the PET differed between the different locations. As mentioned in Chapter 1, the goal was to choose a site where the development would have the greatest impact on the city and its users. Based on the different findings, Wilhelminaplein was chosen as the development site. The main reason for this decision was the high potential the site shows. It is located in a prime location to attract many tourists with a direct connection to the Koningin Emmabrug. The CURACAO and DUSHI signs are already attracting tourists, but because of a lack of activities and cool sitting spots, it is not used as more than a location to take photos. The small stage was also often mentioned during interviews as having high potential value, but it is currently not being used much due to the heat.

Chapter 5

Site Analysis

In this chapter, Wilhelminaplein and its surrounding area is analysed. This will include an overview of the current state of the square in Section 5.1 and a brief history of the square in Section 5.2. The roads around Wilhelminaplein are analysed in Section 5.3. The water management with regards to groundwater and potential flood risk are analysed in Section 5.4. The target group of the redevelopment of Wilhelminaplein is defined is Section 5.5. Finally, the gathered information is analysed using the SWOT method, which can be seen in Section 5.6.

5.1. Current State of Wilhelminaplein

Wilhelminaplein is located in the centre of Punda, at the intersection of Breedestraat and the road towards Pietermaai. Due to its central location, it is a common stop for tourists. The square has a surface area of around 2,980 m^2. A schematic overview of the square can be seen in Figure 5.1. A collection of pictures can be seen in Appendix L.

The most iconic landmarks on the square are the CURACAO sign on the north-west side, the DUSHI sign on the south-east side, and the statue of Queen Wilhelmina. Just behind the CURACAO sign, there are small stands originally meant for vendors to set up their shops. These stands are currently never used [10], but they do provide some shade. People are occasionally observed sitting on them, although they are too high to be comfortable. North of the square, across the road, there are terraces belonging to cafes, along with an ice-cream shop, with the back facing the square. Towards the west and the south of the square, there are mostly government buildings, many of which are denoted as historical monuments by UNESCO [49].

Towards the west side of the square, there is a small stage. This stage is used for a variety of events, especially on Thursday evenings during the weekly "Punda Vibes." To the east, there is a statue of Queen Wilhelmina, surrounded by a dirt patch, which stretches towards the DUSHI sign. The patch was originally intended to be covered with grass, but in recent years, irrigation has ceased, leaving it dry and barren.

In the centre of the square, there is a blue circle on the ground, which is a remainder of the fountain that used to be there. It currently serves no purpose and looks out of place. Some trees are scattered around the square, including *Tabebuia heterophylla*, *Guaiacum officinale*, *Swietenia mahagoni*, *Sabal palmetto* and *Terminalia buceras*. The north side features some large old trees, likely *Swietenia mahagoni*, but some have been removed or have died in recent years [60]. At several locations on the square, there are benches. Some benches are partially shaded by trees, especially towards the south-west side. Other benches are fully exposed to the sun. On the south-east side, there is a small play area featuring iguana sculptures. Kids do not often use this play area.

Towards the eastern side of the square, there is a large canopy-like structure featuring some trees. This structure offers a considerable amount of shade, yet it lacks the necessary facilities to serve a clear purpose. People can often be seen there, either standing, sitting on the ground, or sitting on their personally-brought chairs. The entirety of the square is surrounded by a road, which experiences a considerable amount of traffic.

The west, south and east sides of the square feature some parking spaces. Towards the west and east, there are also larger car parks.



Figure 5.1: Map of the current state of Wilhelminaplein and Hendrikplein

5.2. History

At some point in the past, before the renovations in 2009, Wilhelminaplein was a vibrant green park with trees on the outside and grass in the middle. Photo records place this former shape of the park at at least 1970 [61]. In the centre of the square, there was a fountain, the remains of which can be seen today. Wilhelminaplein was originally called Wilhelminapark, but that name was phased out over the years due to the more square-like design. More photos of Wilhelminaplein in the past can be found in Appendix L.



Figure 5.2: A colour photographic postcard with an aerial view of Wilhelmina Park in 1970 [62]

5.3. Routing

Figure 5.3 shows the routing of different modes of transport around Wilhelminaplein. The Primary car route circles the square past all possible parking spots. The car parking around Wilhelminaplein is an attractive location to park in the Inner City. Other vehicles proceed to Punda via the Breedestraat (top left). Many stakeholders have issued the wish to make this street car-free. So in the future, the number of cars that use this street will likely decrease to only emergency and delivery vehicles [56].

The main stream of pedestrians also arrives from the Breedestraat, often to visit the CURACAO sign. From there, they either move across the square or into the Columbusstraat (top middle).

The biggest issue with the current circulation is where the pedestrians from the Columbusstraat or the Breedestraat cross the road to the square. There are no zebra crossings, so they have to wait until there are no cars or wait for a car to let them cross.

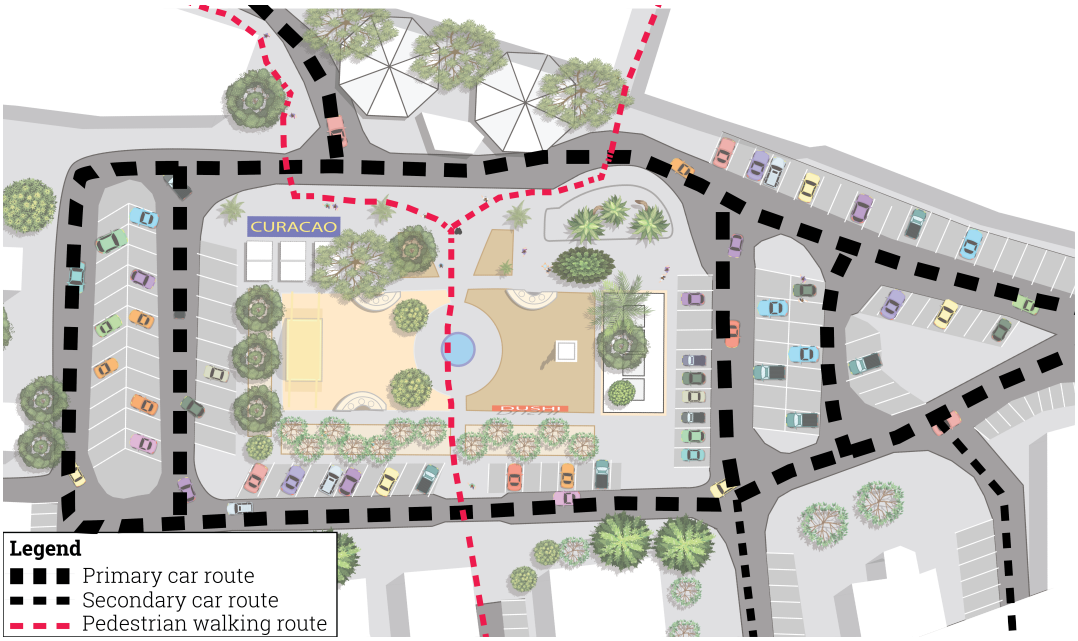


Figure 5.3: Routing with different modes of transport

5.4. Water Management

Groundwater Salinity

Wilhelminaplein is located in the Ser'i Domi Formation, where the soil consists of limestone and coral-based materials [63] [64]. Wilhelminaplein is located around 100 m from the nearest coast towards the south. Due to the high hydraulic conductivity associated with limestone-based soil [65], water from the sea can freely flow through the aquifer, mixing with fresh water, causing the groundwater to be brackish [66].

Research performed in 2020 found that the majority of groundwater in the eastern part of Curaçao is classified as brackish water [66]. Brackish water, while still being less salty than seawater, is not suitable for most types of plants. Water with high salt concentration can cause significant problems in fountains and other systems due to salt deposits and corrosion within the pipes [67]. As such, the use cases for brackish water are limited to that of salt-resistant plants. Due to the relatively high irrigation costs, it is recommended to introduce plants that can thrive in brackish water and require as little irrigation as possible.

Flood Risk

Despite being relatively close to the sea, Wilhelminaplein and its surroundings are not at direct risk of flooding. During extreme precipitation events, the area has historically not been at risk of flash floods. While coastal flooding is a bigger danger for the Inner-City, Wilhelminaplein is not a high-risk area: Figure 5.4 shows that even a 4-meter storm surge would likely not affect Wilhelminaplein.

Therefore, interventions designed to mitigate the impact of flooding have a relatively low priority for Wilhelminaplein.

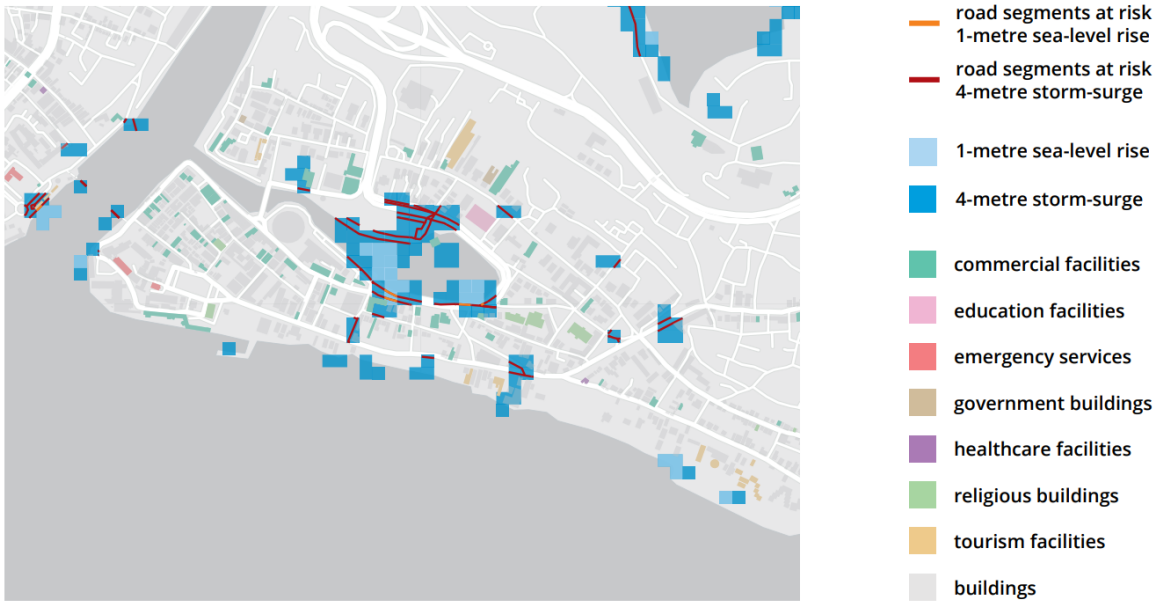


Figure 5.4: A map of Curaçao showing which areas in Punda are prone to coastal flooding for both a 1-meter and 4-meter storm surge [29]

5.5. Target Group

For the redevelopment, it is important to keep in mind who the target group is and who the users of the area will be. To keep all stakeholders satisfied, the design should not cater towards a specific group of people. This means that the target group consists of the people living in Punda, tourists, and all other island residents. These are people of all ages and nationalities. Currently, the square is mainly visited by tourists; for local inhabitants, it has little to offer. In the redevelopment, it should be clear that one of the goals is to provide an area that is attractive to both tourists and inhabitants of Curaçao. The municipality aims to increase the number of people living in Punda. Developing an area that makes it more pleasant to live in Punda could help attract more people. It is important to recognise that tourists and people living in Punda have different demands for an attractive square and that both of these have to be incorporated.

5.6. SWOT Analysis

Based on personal observations, interviews with stakeholders, and an analysis of the site, a SWOT overview was created (Figure 5.5). The map shows the specific locations that the SWOT refers to. This overview highlights all strengths, weaknesses, opportunities and threats relevant to the square and the project. These will form the basis for the design proposals by holding on to the strengths, improving the weaknesses, seizing the opportunities, and being mindful of the threats. Most important are the first three opportunities. Turning the square into a cool spot, hotspot and meeting spot forms the base of the designs. These ambitions are linked to the goals set in the earlier Chapters of improving Heat stress, water management and socioeconomic issues.

Strengths	Weaknesses	Opportunities	Threats
1. Attractive location in the city 2. CURACAO & DUSHI signs attract many tourists 3. Stage can be used for performances 4. Square has a historical value 5. Square is not prone to flood risks	1. Barely any shadow 2. Sand patch and fountain remainder are unattractive 3. Cars drive around the square 4. Vendor stands are hidden behind CURACAO sign and therefore not used 5. Canopy lacks function 6. Ice cream shop is unattractive as its backside is facing the square	1. Square could function as a cool spot 2. Square could funtion as a meeting spot 3. Square could function as a hotspot 4. Square could have great ambiance with good lighting 5. Constant eastern wind could be utilized 6. Square could function as entrance to Punda 7. Cars could be rerouted to create more pedestrian area 8. Parking spots can be rearranged (whilst keeping same amount) 9. Information point could attract visitors	1. Previous initiatives have stopped due to lack of funding/ maintenance 2. Square tries to fulfill several functions but succeeds at none (Performance space, meeting spot, vendor area) 3. Many different stakeholders could lead to difficulties for implementations



Figure 5.5: SWOT overview

Chapter 6

Possible Solutions

In this chapter, several possible solutions are explored that have the potential to solve or mitigate the problem of heat stress, while keeping water management in mind. In Chapter 7, these ideas are translated into implementable interventions.

6.1. Shading

One of the most important factors in the calculation of PET is radiation. This radiation component can be limited by introducing shade. As such, shade plays an important role in making the square more attractive. Natural and artificial shading have a comparable effect on the thermal indices like PET [68] [69], but they differ in their use and have different advantages.

Natural Shading

Natural shading by trees or other plants has many advantages. Not only do plants look pleasant, they also cool the air through evapotranspiration. Vegetation, if native, is great for the local ecology and can provide shading without support structures.

The effect of vegetation on the airflow is still a topic that requires research. Trees can block the wind. Reducing wind speed has a negative impact on the PET. The magnitude of this is hard to determine.

Artificial Shading

Wilhelminaplein is already equipped with several examples of artificial shading. Namely with the canopy on the eastern end, and the stage and stands on the western end. In the middle of the square, there is still unrealised potential for shading. Appendix F.4 shows different reference projects where artificial shading is created, for example, with the use of plastic circles above a town square or with cloths suspended above a market. These references display aesthetically pleasing ways to create shading in open areas. As shown in Figure 6.1, this type of shading is already used in Willemstad.

The advantages of artificial shading over natural shading are that:

- They require less maintenance;
- They can be removed more easily for an event that requires open air;
- They can incorporate local art, as in the Beenleigh example (Appendix F.4);
- They only need support on the edges and can therefore cover a bigger area without obstructions.



Figure 6.1: Shading near Freedom Hotel, Otrobanda

Water Usage

Proper use of water is an important aspect of climate resilience. Open water cools the surrounding area through evaporative cooling, making it an effective tool to lower the PET of any urban area. As explored in Chapter 2.2, fresh water in Curaçao is relatively expensive due to the cost of desalination treatment and the lack of freshwater sources. In recent years, after the redevelopment in 2009, all water facilities on Wilhelminaplein, including the fountain and irrigation, have ceased. It is likely that this is due to the relatively high fresh water costs, with no party willing to pay. For these reasons, it is crucial to carefully asses the use of drinking water and to explore which alternatives are present.

6.2. Fountain

From as early as 1970 (see Figure 5.2), Wilhelminaplein has featured a prominent fountain in the centre of the square. The fountain had an estimated surface area of around 15 m^2, going by the picture in Figure 6.2. In recent years, this fountain has ceased to be used. This fountain has now been removed due to water quality concerns. Due to an outbreak of dengue, there were worries that the water inside the fountain would form a hotspot for mosquitoes while the fountain was inactive, causing it to be removed entirely [10]. Fountains, however, are one of the most effective measures to combat urban heat stress [70]. They are, therefore, still worth considering.

In this work, two types of fountain are considered: a wet fountain and a dry fountain. Wet fountains, like the one originally present on the square, contain a visible basin or pool filled with water, which flows continuously through jets or spouts. Wet fountains circulate a lot of water. Most water losses are due to evaporation. Average evaporation in Curaçao is 7.2 mm/day [31], meaning that a wet fountain of 15 m^2 loses 110 L per day or 39,000 L per year. This results in a water cost of 550 ANG/year. This does not account for any water spilt from the fountain basin and water evaporating before reaching the basin. A wet fountain requires a lot of maintenance, with most work going into cleaning, inspection and descaling [71].

Dry fountains do not have a pool of water; instead, they use high-pressure nozzles to spout water into the air, after which the water falls on the ground and exits towards flows into a drainage system. Typically, the water is then recirculated, making a dry fountain very efficient in terms of water usage compared to a wet fountain. They can also be programmed to only be active at the hottest hours. The water losses consist of a combination of evaporation, wind drift, and splash out, all of which combined are estimated to be around 5 % of the daily water usage, around 50 L/day or 18,000 L/year. This means the water costs would amount to around 260 ANG/year. To ensure that the water quality remains up to standards, the recirculated water is commonly filtered, treated with chlorine, and potentially exposed to UV light. As such, a dry fountain typically requires even more maintenance than a wet fountain.

Dry fountains can provide an attraction, since people can enter the fountain area. Especially for kids, a dry fountain provide a playful and refreshing area [72].

Open water, like a fountain, pond or canal, is known to decrease the surrounding temperature, reducing average daily air temperature by up to 1 °C [73]. A large fountain with 45 nozzles has a strong effect of 2-6 °C on downwind temperatures over a large area [74]. While smaller fountains may have a more localised impact, they can still effectively cool the air, lowering PET by around 3 °C [70] [75].



Figure 6.2: Left: The old fountain located in Wilhelminaplein [76] Right: A dry fountain in Riffort in Otrobanda, Curaçao [77]

6.3. Misting System

Misting systems are highly effective in improving thermal comfort by significantly lowering Physiological Equivalent Temperature (PET) in outdoor environments. Misting creates small water particles, which evaporate very efficiently and can lower the skin temperature when coming into contact with it. The thermal sensation of people influenced by misting decreases drastically [78].



Figure 6.3: Left: A set of misting poles on a playground [79] Right: A close up of a misting pole [80]

For instance, in Tempe, Arizona, the combination of misting and shade reduced PET by up to 15.5 °C in a hot dry climate. This demonstrating the substantial impact of evaporative cooling. Long, flexible, narrow piping systems were used, with multiple nozzles positioned to spray a fine mist downward toward users in the outdoor seating areas of five restaurants. Only misting without shade reduced PET by 6.5 °C [81]. In a humid climate, the MIST-DRY system, tested at a railway station, achieved air temperature reductions of 1.63 °C to 1.9 °C during peak heat hours [82]. Operating in cycles of 2 minutes on and 3 minutes off to prevent surface wetting. The energy efficiency of these systems is notable, as they can operate with a Coefficient of Performance (COP) significantly higher than traditional air-conditioning.

COP is defined in formula 6.1. Depending on the size of the installation, the COP varies from 50 (small) to 300 (large) [82], [83]. A normal air-conditioning unit has only a COP of 5. A nozzle uses around 1-5 L/h, depending on size and on-off strategy [84], [85], [86]. The pump input power, when declared, ranged between 30 and 1500 W, while the developed pressure varied between 0.3 and 7 MPa. high-pressure systems around 3 MPa should be preferred to generate droplet diameter below 40 µm [85].

$$\mathrm{COP} = \frac{Q_{\mathrm{evap}}}{W_{\mathrm{input}}} \tag{6.1}$$

For optimal performance, misting systems require specific environmental conditions, including relative humidity below 70 % and temperatures above 30 °C, with wind speeds under 3 m/s [85]. In tropical conditions, mist systems are effective between 10 am and 3 pm [86]. A minimal windspeed is needed, as with wind still conditions, the mist is not distributed [84]. Optimal wind speed is 1 m/s [85]. The distance from the misting source also affects cooling efficiency; while misting fans can maintain high cooling until 4 meters, the effect closer to the cooling system is much bigger [82]. Staying too close could lead to surface wetting [87], [78].

For Wilhelminaplein, misting systems are an interesting option as temperatures are often above 30 °C with relative humidity below 70%, confirmed by the METEO station in Punda [31]. Wind speeds on Wilhelminaplein are highly variable, but the measurements in this study show often wind speeds below 3 m/s, see Appendix D. A control system that uses real-time wind, relative humidity, and temperature data to check if the conditions are met would be preferred. This system should also control the flow rate and adjust it to the meteorological conditions.

An estimate for the initial cost of five misting units with a radius of 10 m was found to be around ANG 15,000, not including installation [85]. It is important to note that this estimate can vary based on supplier and availability. The water and power usage are estimated at 2.75 Liters per hour per nozzle and 7.5 W, respectively, per nozzle. Assuming a total of four poles with 4 nozzles each, active for 2.5 hours per day, this results in total water usage of around 40,000 L per year and energy consumption of 110 kWh per year [88]. Current water and electricity rates of 0.0144 ANG/L and 0.7623 ANG/kWh, respectively [33], puts the estimated usage cost at 1.80 ANG per day or 660.00 ANG per year.

It should be noted that a misting system also requires regular maintenance, especially due to salt spray affecting the electronics.

6.4. Vegetation

Vegetation, such as plants and trees, is an important component of any public square. They increase the visual appeal of the park, provide shade, increase the water retention capacity of the soil and increase biodiversity. In addition, they also provide cooling through evapotranspiration. Due to the problem of water scarcity in Curaçao (see Section 2.2), it is advised to limit the need for freshwater irrigation by exploiting the brackish groundwater underneath the square. This can be done by planting local vegetation that can thrive in brackish water and is drought-resistant.

Ground Coverage

As stated in Chapter 5, the square was initially designed to have patches of grass which have dried out due to lack of irrigation. In Figure 5.2, it can be seen that before the redevelopment in 2009, the park was filled with a green grass field. Because of the high irrigation costs of typical lawn grass, it is advised to use a local type of ground coverage with better resistance to brackish water and drought instead.

There are around 30 grass types native to Curaçao [89] and even more alternative types of ground coverage. These types of ground coverage are filtered on appeal, brackish water tolerance, and drought resistance. Three plants that best fit the above criteria are shown in Table 6.1. A picture of each can be seen in Figure 6.1.

The plants that are deemed the best ground coverage for the redevelopment of Wilhelminaplein are the Bermuda grass (*Cynodon dactylon*), the seashore dropseed (*Sporobolus virginicus*) [91] and the Banana di Rif (*sesuvium-portulacastrum*) [92].

Bermuda grass serves as an excellent alternative to typical lawngrass. It is known to have a low water consumption and a relative resistance to brackish water [93]. Because of its green colour, it has the same appeal as typical grass. It is also very walkable, making it a good option for areas that expect

Table 6.1: Types of ground cover local to Curaçao filtered on appeal, brackish water tolerance, drought resistance, and walkability [89] [90]

Name	Brackish Water Tolerance	Water Usage	Walkability
Bermuda Grass	Moderate tolerance	Low	High
Seashore Dropseed	High tolerance	Low	Moderate
Banana di Rif	High tolerance	Low	Low

heavy foot traffic. During the initial growing period, Bermuda grass does require extensive irrigation. After settling, the grass is likely able to live exclusively on the brackish groundwater.

Another excellent option is the Banana di Rif. While not a type of grass, Banana di Rif is known as a beautiful ground-covering plant with pink star-shaped flowers. Because it often grows near the coast, it is very resistant to brackish water and requires very little water [92]. It is, however, somewhat fragile to foot traffic and should, therefore, be avoided in areas where people are expected to walk [94].

Lastly, seashore dropseed is also an excellent choice. Being a grass type that can often be found near the coast, it has a very high tolerance for saltwater content and requires very little water [91]. It can handle people walking on it in a limited capacity.



Bermuda Grass [95]



Seashore dropseed [96]



Banana di Rif [97]

Figure 6.4: Plants recommended for Wilhelminaplein

Trees

Trees are a great addition to any urban square, providing shade, cooling and increased water retention capacity. As explored in 5, there are currently already some trees on the square. The most potential is to place more trees in the centre and on the patch surrounding the Wilhelmina statue.

A possible intervention to draw more people into the square and to create a cool zone is to add a big tree to the centre of the square, surrounded by benches. Since this centrepiece tree aims to draw visitors to the square, it should be very visually appealing and provide enough shade to cover multiple benches.

To select which trees are to be used in the design, the following criteria are formulated: the tree must provide ample shade, be resilient to brackish water, require relatively low upkeep and irrigation, do not bother passers-by (for example, through toxicity or pests) and not damage the surrounding area. The centre tree also has the added criteria of having a very high appeal, as to draw visitors towards the square.

In correspondence with a representative at Carmabi (The Caribbean Research and Management of Biodiversity foundation)[98] and Vivian's Nursery, a local plant nursery [99], three trees that best meet the above criteria have been selected.

The Indju (*Prosopis juliflora*) (see Figure 6.5) is an excellent choice for a centrepiece tree, as its large height at 12 m [100] and wide 'spreading crown' shaped form means the tree provides shade to a

very large area [101]. In addition to this, the tree can survive very well in brackish water and is native to Curaçao. The Indju also requires very little maintenance and irrigation once it has settled, making it an ideal low-maintenance tree [102]. Because it does have sharp thorns along its branches, especially when young, some pruning may be necessary to remove lower branches to prevent injuries. Once the tree reaches maturity, the canopy typically grows high enough that the thorns are out of reach, reducing the need for further management [102]. Despite their large size, the Indju tree grows relatively quickly, likely reaching maturity in 5-10 years [101].



Figure 6.5: The indju [103]

Trees used for the rest of the square include the green buttonwood (*Conocarpus erectus*) and the Oleifi [1] (*Bontia daphnoides*) , see Figure 6.6. Both trees serve the above criteria and are visually appealing.

The green buttonwood is a local type of mangrove tree. The tree is sometimes called mangel blanku colloquially, although this name is often also used for other local trees [104]. The green buttonwood is an ideal shade tree because it remains green year-round and grows relatively quickly.

In addition to the green buttonwood, another variant, *Conocarpus erectus sericeus*, can also be used. This tree is very similar to the green buttonwood, but it has gray leaves, providing an option for variety [98].

The oleifi is a local type of shrub that can grow up to 5 meters tall [105]. Despite not being a true tree, the oleifi resembles a tree in shape and provides both shade and an attractive visual appearance. It can be used as a solitary 'tree' or planted in groups to form a hedge [99].

[1] The *Bontia daphnoides* is technically a shrub, not a tree.



The green buttonwood. [106]



The oleifi. [107]

Figure 6.6: Two trees that are proposed as an addition to the square

To ensure that the growing tree roots do not damage the surrounding infrastructure, root barriers should be installed. This will ensure that the roots extend downwards before spreading out, ensuring that the roots stay below the pavement.

6.5. Pavement

The pavement material is of great influence on the radiation balance. All materials have different properties that affect the temperature. In general, there is not one best material, as some properties are more effective during the day and less so during the night, and vice versa.

Albedo

Materials with high albedo reflect more sunlight. This increases the radiation budget on a person. The *mean radiant temperature* T_{MRT} or shortwave radiation increases. The material, however, absorbs less heat, resulting in a lower *surface temperature* T_S, decreasing longwave radiation from the surroundings. Materials with low albedo, on the other hand, absorb more solar radiation, increasing the T_S, and decreasing T_{MRT} [108]. Both T_{MRT} and T_S affect the PET, as stated in Figure 2.4.

Which of these effects is strongest is not always clear, but most research suggests that the increased T_{MRT} is dominant. In these studies, a higher albedo inducing higher reflection led to lower air temperature but a higher PET, so lowering thermal comfort for pedestrians [109] [110] [111].

Heat Capacity

The heat capacity of the pavement material mainly affects the magnitude of the Urban Heat Island effect. Materials with high heat capacity absorb more heat, but they also release it more slowly. During the day, the air temperature is lower, which becomes evident from the most simplistic Surface Energy Balance, Eq. 6.2:

$$Q^* - H - L_v E - G = 0 \tag{6.2}$$

Here, the radiation budget Q^* is balanced with the sensible heat from the surface H, latent heat/evapotranspiration $L_v E$ and ground heat storage G. Increasing G would result in a decrease in H (assuming $L_v E$ is not affected as much) [112]. In the evenings, however, it can stay warm for longer

near these materials, while low-capacity pavements cool off. This delay in temperature exchange between pavement and air determines the Urban Heat Island effect, which compares the air temperature in the urban environment to that of the surrounding rural environment. Since this report focuses on mitigating the maximum temperatures during the day, materials with high heat capacity are preferred.

Permeability

Permeable pavement is a sustainable option for both water management and heat stress. During precipitation events, water can recharge the aquifer below through the pavement, replenishing the groundwater table [113]. This groundwater can, in turn, be used for irrigation. In case of an intense precipitation event, permeable pavement allows the soil to act as a buffer, decreasing surface run-off and reducing flood risk. This also alleviates stress on the sewer system during precipitation events. In addition, permeable pavements can also induce an evaporative cooling effect for both the air temperature and surface temperature [114]. A field experiment has found an average air cooling effect of 0.2 °C to 0.45 °C and an average surface cooling of 1.2 °C to 1.6 °C under wet conditions [115]. During dry conditions, however, there are no added effects of evaporative cooling, limiting the effectiveness in addressing the heat island effect in semi-arid regions like Curaçao. Permeable pavements are also slightly more expensive than regular pavements and require more maintenance.

Design Proposals

The different pieces of analysis were transformed into three design proposals, each focusing on one specific design solution. The design proposals can be found in Appendix J. Two meetings were planned to receive feedback on these designs, one with C. Vierbergen and Z. Garmers from Zarja Architecture and one with R. Gabriela from ROP. Meeting with Zarja Architecture was crucial as they are more practised in designing public space, and their fresh perspective on the square helped give insight into the different possibilities. The meeting with ROP was especially useful in making sure the design complied with the EOP ([116]). After these meetings, the interventions were fine-tuned, and the designs were finalised.

The design proposals were divided into three different designs, but the final designs can be seen rather as different combinations of the interventions. These interventions are divided into three categories: minor 'quick-win' interventions that have a high impact in return for a low investment cost, large investments that provide the square with a cool spot, and extra interventions that can be introduced on and around the square. An overview of the different interventions will be given, combined with impressions of what the square might appear if these were to be implemented.

Chapter 7

Proposed Interventions

This chapter proposes a set of interventions that are beneficial for the square. These interventions will range in price, cooling ability, water usage, attractiveness and level of maintenance. The interventions are divided into quick wins, cool spot interventions, and extra interventions.

By proposing different solutions, the ministries can choose which solution they deem the best fit for the square.

7.1. Quick Wins

This section covers the interventions that have relatively low initial and maintenance costs whilst making a large impact on the usability and liveability of the square. Most of these interventions are also quick and easy to implement, making an immediate impact.

Connecting the Canopy

One of the square's weaknesses is the canopy located on the eastern side of the square. It currently lacks any function as there are no sitting options, and it is not connected to the square. It does have a lot of potential as the trees grow through the roof openings, which makes it a cool and green spot. To make it more attractive, a better connection with the square is needed. To accomplish this, a walkway from the centre of the square to the canopy is proposed. This would be combined with adding sitting options to make it a more attractive meeting spot. All three designs aim to bring life to the dry field around the Wilhelmina statue. Through the middle of this green field, a walkway would lead visitors past the statue and into the canopy. Figure 7.1 shows how this would look.

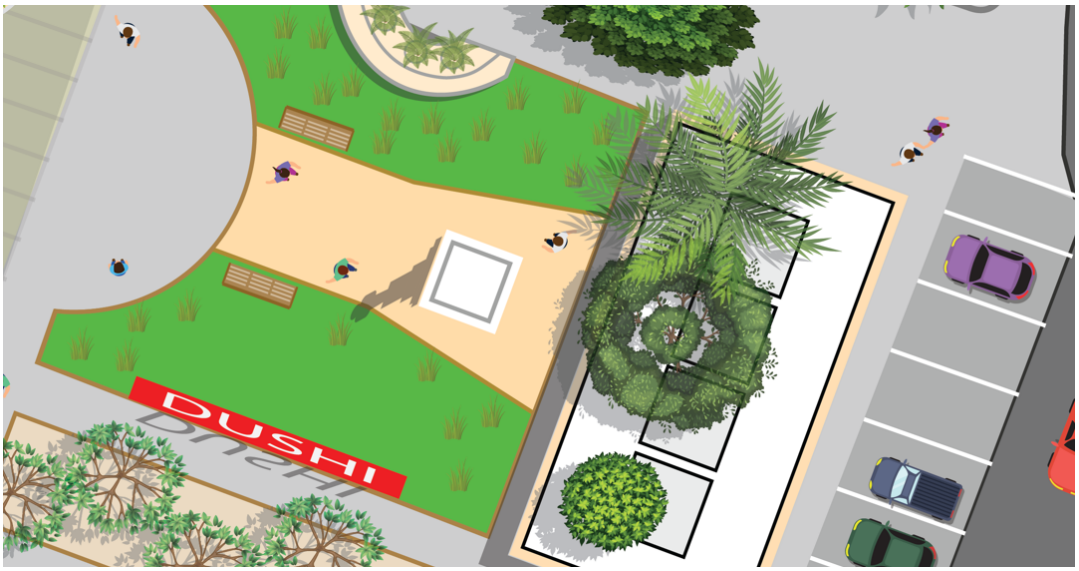


Figure 7.1: Path to connect the canopy



Figure 7.2: An impression of how the canopy would look after placing benches

Even though this intervention would provide the canopy with a function, it still forms a barrier between the parking on the eastern side and the rest of the square. In the event of a large concert, the people who would be standing in the parking space would not be able to see past the canopy. Therefore, another option to improve this space would be to remove the canopy entirely. This would remove the barrier for people who enter the square from that side. The trees could be left intact, and the ground could be turned into a field of grass. This way, the area would still be connected to the rest of the square whilst opening it up to the parking spaces on the east. The removal of the canopy would cost around ANG 10,000. The PET would increase at this location with 4 $°C$ due to a reduction of shadow, for more information see Appendix E.

Greening the Field

One of the primary contributors to the deterioration in visual attractiveness is the sand field around the Wilhelmina statue. What was once a tidy patch of grass is currently no more than a dry field of sand with an occasional irrigation outlet to remind us of the green field that must have been there. A lack of maintenance and irrigation and possibly a wrong plant choice are the reasons for the area being in the state that it is in now. This area will be planted with Bermuda grass, which has been identified as the optimal choice for walkable ground coverage 6.4. This is due to its resilience against being walked on and its tolerance of brackish water. It is a low-maintenance option that has a high likelihood of surviving, along with a pleasant and neat appeal. The smaller patches of sand towards the entrance and the area around the palm trees will be filled with Banana di Rif. This plant is less resilient than the Bermuda grass but is more attractive during its blossoming season. It has the appearance of a delicate flowerbed, so people will stay off of it. This plant also survives on brackish water, so little maintenance is needed. Next to the addition of the Banana di Rif and the Bermuda grass, extra trees, namely the green buttonwood and the oleifi, are added to the field, and new patches of greenery are added to the corners of the square. Just as with the Banana di Rif and the Bermuda grass, the trees are local species and have the ability to grow on brackish water. In the initial period following planting, the plants will require some maintenance, but after this, they will be able to grow independently. On the added patches of Banana di Rif these trees will also be planted. This will make the square more inviting from all sides. For a detailed map of this intervention, see Figure 7.3. The PET decrease at the field is between 4-7 $°C$, the PET decrease for all locations can be found in Appendix E.

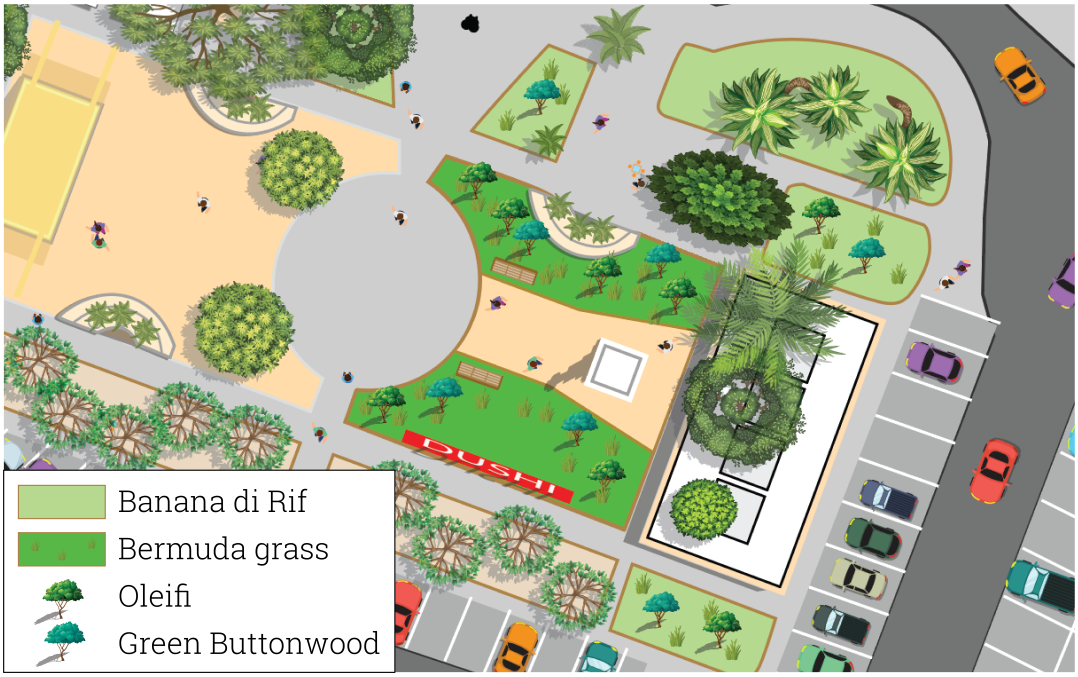


Figure 7.3: New greenery on the field

It is still possible to reach the DUSHI-sign as the Bermuda grass is resilient to being walked on. Nonetheless, there is the chance that the grass on that side will have a less lively look than the grass not being stepped on as much. In an extreme case, a new path will be formed by the users from the square to the sign.

Revitalise Plants in the Benches

The third general intervention is bringing back the plants in the benches. In the previous redesign, three large sitting structures were introduced, and irrigated planting pots were incorporated into them. Unfortunately, the plants have not remained in their expected state as barely any of the pots are currently filled with plants (Figure 7.4). Most of the openings are filled with trash, leaving the benches entirely without shadow. Revitalising the benches bring back a pleasant meeting spot to the square.



Figure 7.4: Plant benches before (left) and currently (right) [117]

The reason for the dying of the plants was a lack of maintenance and irrigation. To revitalise them in the new designs, a better maintenance schedule will be proposed with a clear party responsible for them. With better maintenance, the plants will grow again, making it possible to sit in their shadow again.



Figure 7.5: An impression of how the square would look after connecting the canopy, greening the field, and revitalizing the plants in the benches

Turning the Vendor Stands into Seated Tables

The vendor stands currently provide ample shade. They are never used by vendors, mainly because they are blocked by the CURACAO sign. Since they do however create some shade, the structures can be repurposed as tables by adding benches and chairs. These tables can then be used for people to sit in the shade and eat, relax or play games like dominoes.



Figure 7.6: An impression of how the current vendor stands would look after implementing benches

7.2. Cool Spot

The primary issue with the square is that during the day, it becomes incredibly hot without providing many cool spaces 5.5. Most seating options are not attractive because of a lack of shadow created. This is seen as the main reason for visitors not being attracted onto the square and staying there for a longer time. By providing cooling to the current seating options and adding new seating possibilities, the cool spot and meeting spot aspects are combined well. Therefore, the main priority is to provide the square with a cool spot that attracts visitors. To achieve this, three possible interventions are proposed.

Misting System

The first option is to construct a semi-transparent structure combined with a misting system around a circle of benches. This octagonal structure combines four misters with a 120° range aimed to the middle, with one 360° mister in the centre of the structure. The combined spray area fills the entire structure and all benches beneath it. The semi-transparent shading structure would be made out of insulating material that blocks the radiation of the sun. This could be done with special insulating tarps or wool structures such as in the Sebastopolstraat (4.2). The shading would be designed in cooperation with local artists, as is often done in the Inner-City.

This cool spot would attract visitors to the square by its inviting design and by providing a spot to cool down. This cool spot will also keep them on the square longer as it is one of the few cool spots in Punda. The structure will impact the stage function of the square. As mentioned, one of the current functions of the square is to provide a stage for concerts and gatherings. The structure will have a height of four meters, so the view will not be obstructed by the people standing beneath and behind it, but the construction and the benches will reduce the number of standing places, but only slightly, as people can stand on the benches. This is also done with the benches in the current situation. Figure 7.7 shows what this would look like on the square. The initial cost of the five misting poles and a shadow cover is approximately ANG 50,000 with annual water and electricity expenses around ANG 1,400. The system will also require periodic maintenance, especially due to the salt spray from the nearby coast [118]. The decrease in PET in the middle of the system is more than 10 $°C$. The PET decrease for all locations can be found in Appendix E.

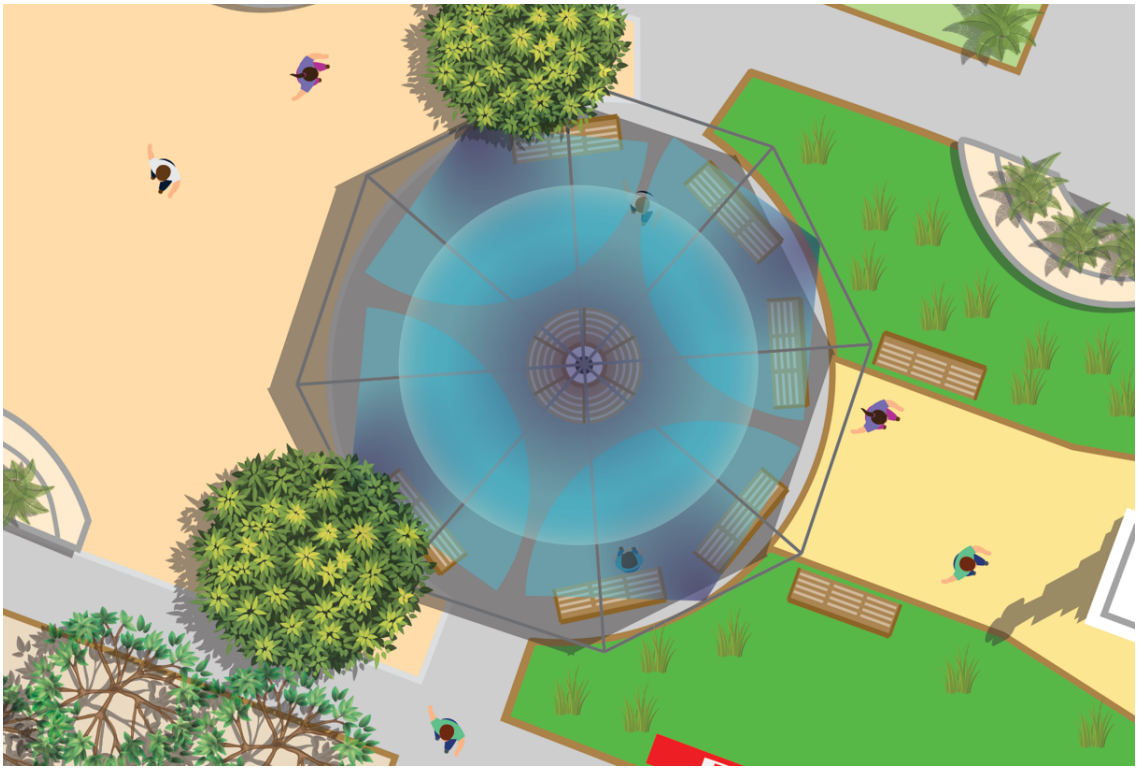


Figure 7.7: Cool spot option 1: misting system



Figure 7.8: An impression of how the centre of the square would look with the misting system and shadow cover

Centrepiece Tree

The second option focuses on turning the square into a green park. As the main attraction point, a large Indju tree will be placed in the centre of the square, with benches placed around it. With its broad shape, it is ideal for providing shadow. This will turn the centre of the square into a great place to meet up. The aim of this design is to lower the PET by adding more greenery and to attract visitors by providing a park within the Inner-City.

The large tree in the middle of the square will impact the stage function of the square. This tree will obstruct the view of the people standing behind it. The benches can be installed in a way that does not affect the overall experience, as they can be used by standing attendees during a concert. Figure 7.9 shows what this intervention would look like on the square. An indju tree can be bought for ANG 450 [99]. Transportation, planting and installing root barriers increases the initial cost to around ANG 2,000. The tree requires some maintenance, such as trimming the branches. Total costs of this intervention is around ANG 12,000, most of which comes from constructing the benches. The decrease in PET by this tree is between 4-7 $^{\circ}C$ depending on location. For more information see Appendix E.



Figure 7.9: Cool spot option 2: Indju tree to provide shadow and cooling



Figure 7.10: An impression of how the centre of the square would look after planting the indju and placing benches around it

Shadow Canvas

The third option focuses on creating a shadow on the western half of the square. This will be done by implementing a large structure, ranging from the stage to the middle of the square. This means the existing benches will also receive shadow. This canvas will be attached to the stage, and using poles at the side, it will increase in height as it reaches towards the middle of the square. This will ensure that it will not feel enclosed beneath it.

Currently, the only time events are held is during the evening because, during the daytime, it is too hot in the middle of the square due to a lack of shade. If this design is implemented, it will also become possible to hold events during the day. It would also make it a more pleasant sitting environment during the day when no events are hosted. The structure would be designed in cooperation with local artists. This will ensure that the design itself will be an attraction point for people to visit the square. Figure 7.11 shows what this would look like on the square. The cost of the shade canvas is estimated at ANG 150,000, with most of the costs being attributed to the structure. The PET decrease under the canvas is between 6-7 $^{\circ}C$ varying per location. The PET decrease for all locations can be found in Appendix E.



Figure 7.11: Cool spot option 3: shadow canvas



The canvas without colour The canvas with colour

Figure 7.12: The podium-side view of the shadow canvas



The canvas without colour



The canvas with colour

Figure 7.13: The square-side view of the shadow canvas

Fountain

As described in Chapter 5, there used to be a fountain in the centre of Wilhelminaplein. The stakeholder workshop revealed that a significant number of stakeholders expressed the wish for the fountain to be reinstalled. Since the reason for the removal of the fountain was a lack of maintenance rather than a lack of interest, building a new fountain in the same place is a valid strategy for a cool spot. To further emphasize the public meeting-spot function of the square, benches are placed around the fountain so that people have a place to sit. A choice can be made between a wet fountain, like the one that was removed, or a dry fountain, which has a lower water consumption (Figure 7.14). The wet fountain is estimated at ANG 30,000 and the dry fountain at ANG 24,000. A fountain has the potential to decrease PET by 3 °C.



Impression of a wet fountain



Dry fountain [119]

Figure 7.14: Different options for fountains on the square

7.3. Extra Interventions

Next to the quick wins and the cool spot interventions, there are several improvements to be made on and around the square that would be beneficial to the liveability, heat stress, and usability.

Permeable Pavement

The introduction of permeable pavement on and around the square has various benefits in terms of water management and heat stress.

Groundwater is a valuable asset in Curaçao (see Chapter 2.2). Increasing the amount of water that enters the soil in the urban environment replenishes the groundwater, which can in turn be used for irrigation. Introducing rainwater to the brackish groundwater below the square will also prevent it from becoming too salty for the plants to thrive in. The limestone soil below the square allows the water to enter the soil relatively quickly. While Wilhelminaplein is not directly at risk from flash floods, implementing a buffer in case of extreme precipitation events reduces the pressure put on the sewage system, reducing the chance of sewer overflow.

Permeable pavement provides a notable cooling effect on both air and surface temperatures during wet conditions. However, since the square is expected to be used primarily during dry conditions and precipitation events are infrequent in Curaçao, this cooling effect is less significant than other interventions. A pavement type with a low albedo is also recommended, as this will also lower the radiation from the surface. The cost for replacing the pavement of the entire square with an permeable material is estimated at ANG 300,000.

Since the existing pavement in the square is in good condition, this intervention should be considered a low priority. It can be implemented when the pavement needs renovation or when pressing water management issues arise around Wilhelminaplein.

Planting Trees near the Parking Spaces

To achieve some cooling near the parking lot, some trees can be planted. This will allow the cars to be parked in the shade, reducing the temperature inside the car and the need for air-conditioning. These trees could be placed in both parking spaces on the eastern and western sides. These trees result in a PET reduction of around 1 $°C$ in the shade.



Figure 7.15: An impression of how the parking lot would look after planting some trees

Solar Car Park

To meet Curaçao's goal of achieving 100 % renewable energy [120], solar panels are a crucial component, offering a sustainable source of energy [121]. Due to Curaçao's abundance of sun, a solar panel in Curaçao yields 1.75 times more energy than one in the Netherlands [122]. The placing of solar panels can be coupled with the charging of Electrical vehicles (EV's) on the parking lots to the west of Wilhelminaplein. Since these parking places are reserved for government employees, they will mostly be used during working hours, during which solar panels produce the most energy. If the demand for electrical vehicles is too low, the solar panels can instead be connected to the power grid.

An important limitation of the use of solar power in Curaçao is the lack of public acceptance of the technology [123]. This is partly due to a history of sudden and unfavourable changes in policies concerning solar panels [122]. Despite this, in recent years, solar car parks have been built on Curaçao, for example, near Playa Porto Mari [124]. Another potential problem for the implementation of solar panels around Wilhelminaplein is a potential clash with the EOP [116] concerning the historical and

cultural identity of the Inner-City. To avoid giving the historical square a ”modern” look, the solar panels should be placed out of sight. Solar car parks can be constructed above the parking spaces, providing space for solar panels out of sight while also offering shade for the cars below. Alternatively, the solar panels could be placed on the roof of the podium or on the roofs of the surrounding buildings.

To supply a typical EV of power, around 4,000 kWh per year [125], 8 solar panels are needed, with a total area of 13 m^2 [126]. To provide power to the entire western parking lot, consisting of 24 parking spaces, a total of 300 m^2 of solar panels is needed. The total parking lot is around 400 m^2. The price for solar panels, along with the necessary batteries for energy storage total around ANG 10,000 per parking space, resulting in ANG 240,000 for the entire parking lot. The solar car park will provide an average power of 11 kW. A solar panel in Curaçao is estimated to have a return period of four to five years [126]. The frame for a solar car park has an estimated cost of 0.7 ANG/W [127], coming to around ANG 7,000 for the entire structure.

It is important to note that a solar car park requires regular maintenance, especially due to the salt spray corroding the electronic components [118].

The initial cost of a 24-car solar car park with enough solar panels to supply all parked EVs with power is, therefore, around ANG 250,000, with a power production of 11 kW and an estimated return period of 5 years. The PET decrease for the parking spots is between 3-4 $°C$. By creating shadow over the cars, the temperature of the cars will be reduced.



Figure 7.16: An impression of how the parking lot would look after implementing a solar car park

Road Rerouting

One of the issues that was highlighted in the analysis is the fact that cars drive around the square in the current situation (5.3). This leads to unclear situations where car drivers must pay a lot of attention to pedestrians who could suddenly cross the street. For this problem, two redesigns for the street situation are proposed.

This issue could be reduced by blocking off the road on the northern side of the square and turning the Breedestraat into a pedestrian area. This would be a minor intervention that could benefit the square greatly. The new pedestrian area could be used for street art and would function as an extension of the square. The parking at the western end of the square will still be accessible by turning the southern road into a two-way street. For emergency vehicles and delivery vehicles, the western pillar

could be opened, but this should not happen too often. Additionally, a zebra crossing is added on the south side of the square to facilitate a safe crossing. Figure 7.17 shows what this would look like.

It is also possible to make it possible for cars to enter the Breedestraat while still re-routing them below the square. Figure 7.18 shows this option. This would still make the square more accessible and safe whilst less impacting traffic flow.

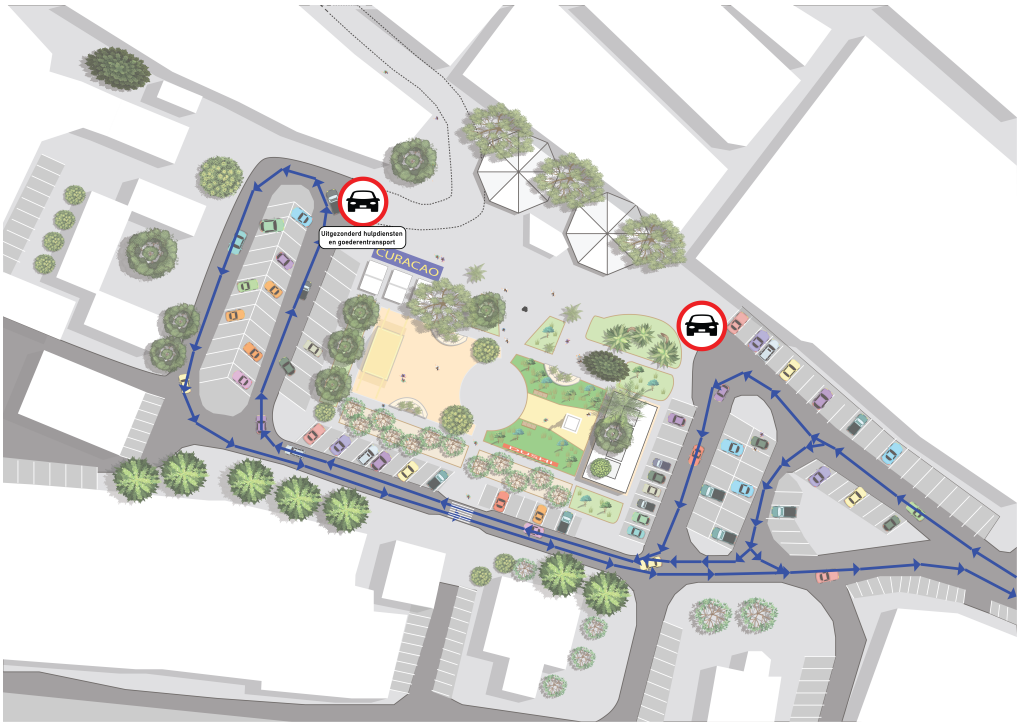


Figure 7.17: Road rerouting proposal A

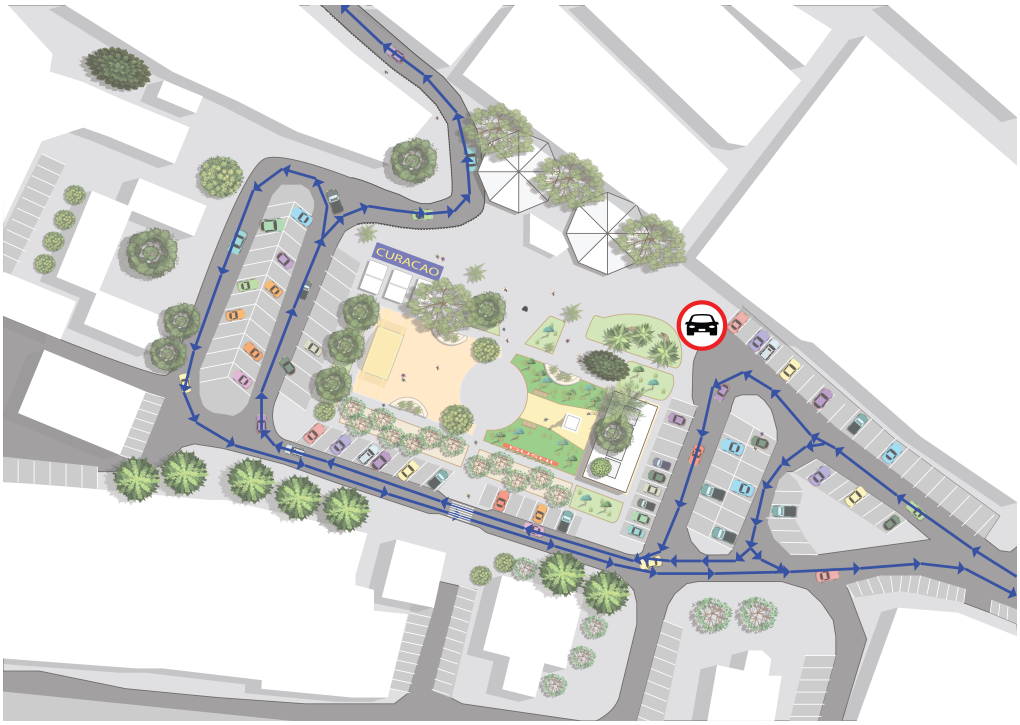


Figure 7.18: Road rerouting proposal B

Transforming the road into a pedestrian area would greatly increase the size of the square. This extra space could be used for many different improvements. One possibility would be to move the Wilhelmina statue to a more prominent location. This would make it possible to completely fill the area where it was previously located with greenery. Additionally, the ice cream shop, which currently has its backside facing the square, can be moved to a more inviting location. Another option would be to add more trees in the pedestrian area or to create more space for the terraces. Figure 7.19 shows what these options could look like. The road rerouting is estimated at ANG 50,000.



Figure 7.19: Different options for the new pedestrian area

7.4. PET Calculations

The PET reductions, as calculated in Appendix E, give an insight into the effects of the proposed measurements. The current situation gives PET values in the range of 50 °C, although these are for extreme meteorological conditions. Trees and artificial shading reduce the PET locally by up to 4-7 °C. The area of influence is dependent on the size of said object. The proposed shadow canvas has the potential to cool the square on a large area. The shading from the shadow cover associated with the misting system design cools a smaller area, but additional cooling can be experienced from the misting, for a total of over 10 °C.

Most locations still experience extreme heat stress or strong heat stress in the design situation. This is even after the interventions. It should be noted that these are for extreme circumstances. With average circumstances, the heat stress experienced should be reduced far enough for low-key activities.

7.5. Overview

In Table 7.1, an overview can be found of the various interventions proposed in this chapter along with their estimated initial cost, local reduction in PET, annual drinking water usage, upkeep, ranked from 1 to 5, and estimated time frame in which the intervention can be completed.

Table 7.1: An overview of the proposed interventions along with their effects, costs and time frame

Intervention	**Costs [ANG]**	**PET reduction** [$°C$]	**Water usage [L/y]**	**Upkeep (1-5)**	**Time frame**
Misting system	50,000	>10	90,000	5	Few weeks
Centrepiece tree	12,000	4 - 7	1,000	3	5 years
Shadow canvas	150,000	6 - 7	0	2	Few weeks
Wet fountain	30,000	3	39,000	4	Few weeks
Dry fountain	24,000	3	18,000	4	Few weeks
Greening the field	12,000	4 - 7	5,000	3	Few weeks
Revitalize plants in benches	500	0	200	3	Few weeks
Connecting the canopy	20,000	0	0	1	Few weeks
Removing the canopy	10,000	-4	0	1	Few weeks
Benches stands/-canopy	10,000	0	0	1	Few weeks
Relocating the Wilhelmina statue	10,000	0	0	1	Few weeks
Rerouting the road	50,000	0	0	1	Few months
Permeable pavement	300,000	0-0.2	0	4	Few months
Trees near the parking spaces	2,000	1	2,000	3	few weeks
Solar car park	250,000	3 - 4	0	4	Few months

Chapter 8

Implementation, Conclusion & Evaluation

To facilitate the practical implementations of the interventions proposed in Chapter 7, some steps need to be taken, which will be covered in this chapter. First, the relevant parties should all agree on a set of interventions, which has been done through a workshop, explained in Section 8.1. Next, necessary research and design steps that are out of the scope of this work, along with permits that need to be applied for, are discussed in Section 8.3. After implementation, a review strategy is proposed in Section 8.4, to retroactively evaluate the effectiveness of the implemented interventions. If the interventions are deemed to be effective, they can be considered for other locations in the Inner-City.

8.1. Stakeholder Workshop

A crucial component for the implementation of the designs proposed in this work is to have the responsible parties, OW, GMN, ROP, and the sector director of VVRP, agree on one idea. From interviews with government officials on the governance culture of Curaçao, it was clear that communication among these parties, along with clear agreements on which party is responsible, is sometimes lacking. To facilitate this communication and gather more opinions from other stakeholders, a stakeholder workshop was given on October 25th. Attendees included representatives from VVRP, OW, GMN, and MEO, METEO, the author of *World of Punda* and a landscaping architect from Zarja Architecture. Students and teachers from TU Delft, Uoc and The Hague University of Applied Sciences were also present. For the workshop the interventions shown in Chapter 7 were incorporated into three designs, shown in Figures K.1, K.2, K.3. All three designs incorporated the 'quick wins', along with either a misting system, centrepiece tree or shadow canvas respectively. During the workshops, said designs were presented along with their corresponding effects on the PET. Afterwards, the stakeholders were placed in groups of 4-7 and were asked to discuss their preferred set of interventions.

The preferences between the different groups were varied, with some opting for ideas with a higher chance of succeeding and others preferring more ambitious plans. All groups agreed that the 'quick wins', rerouting of the road north of Wilhelminaplein, and some type of cool spot should be implemented. Further details on the stakeholder workshop can be found in Appendix H.

One of the groups contained the most influential stakeholders (see Chapter 3): representatives from VVRP, OW, GMN, and MEO, METEO. ROP could unfortunately not be present during this meeting. Since these are the stakeholders that have the most influence on the outcome of the project and have the power to green-light it, their preferred set of interventions was worked out further. Their design can be seen in Figure K.4.

8.2. Permits and Law

Before any construction project can take place, the relevant permits must be approved. Construction permits are granted by ROP. The construction application permit is based on the Island Development Plan and Curaçao's 'Bouw- en Woningverordening 1935' law [128].

The Island Development Plan or EOP (Eilandelijk Ontwikkelingsplan) is a document in which the envisioned long-term developments of Curaçao are described [129] [116]. It proposes general goals like the conservation of valuable assets and the development of a liveable Willemstad. In the principles section, the report names the restoration and development of the Inner-City as a high priority [129]. Article 4 specifically focuses on the Inner-City with goals, strategies, permits and, most importantly

to this project: protecting the cityscape [116]. These form the policies or boundaries within which the design solution needs to stay. The articles related to this project are shown in Appendix I.1.

The Curaçao's 'Bouw- en Woningverordening 1935' law (BWV) is the main law concerning construction on Curaçao [130]. The articles relevant to this work are shown in Appendix I.2

8.3. Next Steps Towards Implementation

Before the chosen design can be implemented, there are some steps that still need to be taken. These are categorised as research, design, and permits. Table 8.1 describes for each intervention:

- **Research:** What information, data or expertise is still needed before the intervention can be done? This can be either technological, social or related to the site.
- **Design:** What parts of the intervention still need to be worked out fully? This entails both visual design and practical details.
- **Permits:** What potential clashes there are that prohibit receiving a construction permit? Any potential clash should be discussed with ROP.

Table 8.1: An overview of the proposed interventions and the steps that still need to be taken in terms of research and design and which laws might prohibit receiving a construction permit

Intervention	Research	Design	Permits
Misting system	It should be investigated where the existing water pipes are located.	The misting system could get a custom design with local art shading.	Potential clash with EOP Article 2.c depending on design.
Centrepiece tree	Maintenance for the tree should be done in correspondence with GMN	-	-
Shadow canvas	A structural engineer should determine the dimensions needed for the construction. A drawing should be provided when applying for a permit (BWV Article 16).	Local art could be incorporated into the shadow canvas.	Building permit required (BWV Article 1.) Should comply with BWV Article 22. Potential clash with EOP Article 2.c depending on design.
Wet fountain	It should be investigated where the existing water pipes are located. A compromise between cooling effect and water usage should be made.	The fountain needs to be designed. It is possible to use the original design. Fountain dimensions and water usage should also be considered.	-
Dry fountain	It should be investigated where the existing water pipes are located. A compromise between cooling effect and water usage should be made.	Nozzle amount, pressure and schedule need to be designed. The fountain at Riffort can be used as an example.	-
Greening the field	It should be checked whether the current irrigation system still works.	The placement and maintenance of trees and plants should be done in correspondence with GMN.	-
Revitalise plants in the benches	It should be checked whether the current irrigation system still works.	The placement and maintenance of the plants should be done in correspondence with GMN.	-

Intervention	Research	Design	Permits
Connecting the canopy	-	The pavement material and colour is still a matter of choice.	-
Removing the canopy	Research should be done on the opinions of stakeholders on the demolition of the canopy.	A plan should be made for what comes in place of the canopy.	Permit needed (EOP Article 3.a)
Benches stands/canopy	Research should be done on how the placement of benches affect the usage of the square by homeless people and addicts.	The benches need to be designed to fit in the area.	-
Relocating the Wilhelmina statue	Research should be done on stakeholders' opinion on the relocation.	The desired location should be considered.	Potential clash with EOP Article 1.a
Rerouting the road	It should be researched whether road safety is guaranteed, even in case of an emergency, as the police headquarters is located on the road. The opinions of store owners in the Breedestraat need to be evaluated, as they are important stakeholders.	The road to the south of the square is now a one-direction road and needs to be broadened in order for two cars to be able to pass each other. This potentially includes removing some parking lots.	Permit needed (BWV Article 42.1.) Potential clash with EOP Article 4.a.1, but potentially possible through EOP Article 1.b.3.
Permeable pavement	It should be researched when the current pavement is in need of renovation. The effects of droughts on permeable pavement should be researched.	The material for the pavement should be decided on.	Permit needed (BWV Article 42.1.)
Trees near the parking spaces	-	Maintenance for the trees should be done in correspondence with GMN	-
Solar car park	The public acceptance of solar panels should be researched. The demand for electrical vehicles should be analysed when building charging stations. The effect of salt spray on solar panels should be analysed.	The structural design for the solar roof should be conducted by a contractor like Ecovolt.	Potential clash with EOP Article 2.c depending on visibility.

8.4. Evaluation

After the interventions are implemented, evaluating how these changes affect the square is important. Reflecting on the development could quantify whether the project was a success, indicate possibilities for similar interventions, and determine stakeholder satisfaction. This section will delve into the methods that could be used to reflect on the development and how this information could be used.

Project Success

How to determine project success is different for each project. This is because the aims and goals differ from project to project. Project success is measured against the overall objectives of the project [131]. These objectives are indicated through the success criteria given to the project [132]. Important to note is that this section will not focus on the project management success but only on the project success. Project management success also takes into account the construction process and can be measured by looking at criteria such as budget and time overruns [133]. This process is outside of the project's scope. Therefore, only the success of the end product will be taken into account. The success criteria for the end product should encompass the different goals and values of each important stakeholder. These can differ between the different stakeholders, but as most of the goals are similar, the success criteria will be similar for most of them. The most important stakeholders to keep in mind are the different ministries (VVRP, ROP, OW, and GMN), the users of the square (Tourists, residents and inhabitants), and the businesses in the area (DMO, surrounding hospitality).

For the different ministries, the main objective is to transform the square into a functional and attractive area that is used more than it currently is. A more attractive square would invite more people, making Punda more lively. For the users, the main objective is for the square to be as attractive as possible and to provide a pleasant meeting spot. Currently, the lack of attractiveness poses a reason not to visit. A more attractive square, would likely encourage more visits. For the businesses in the area, the main need is for the square to attract more visitors. An increase in visitors most likely leads to an increase in revenue.

The attractiveness of the development is based on three factors. The development aims to create a cool spot, a hotspot, and a meeting spot.

Cool Spot

Providing a cool spot is a necessary function for the square. Based on the data and interviews, this is one of the most desired aspects. The definition of a cool spot in this study is an area with noticeably lower PET than its surroundings. If the PET is noticeably reduced and people visit the square to be able to profit from this, the goal of creating a cool spot is achieved. A PET decrease of 3-5 °C is considered a noticeable difference [134]. All reductions over 5 °C can, therefore, be considered significantly cooler. Nonetheless, if the temperature has been lowered significantly without attracting more visitors because of this, the cool spot has not been successful.

As described in the limitations of the measurements, see Appendix D), the measurements conducted for this project are not accurate enough to draw concrete conclusions regarding a PET decrease. To be able to draw such conclusions, the current situation should be measured with better equipment. The recommedations for the measurement method, see Appendix C should be considered for further research. Based on the new measurements, the specific impact of each intervention could also be determined. This could help determine what interventions should be applied in other places in the Inner-City. It could also show how the different interventions cumulatively impact the temperature, as one of RayMan's limitations was that it could not take this into account.

Hotspot

There is also no single definition that a hotspot has to comply with. It is, therefore, not possible to qualitatively determine whether the square has become a hotspot. Hotspots are often places of heightened social interactions and active gathering points. This often comes down to an increased number of people compared to the surrounding area. Based on observations of the current situation, the number of people visiting the square and using it for more than just taking a picture is minimal. To be able to show a definite increase, better measurements are needed. This could be done by monitoring the number of people using the square during the day and keeping track of what they use it for (e.g. taking a picture, resting, meeting other people etc.). By executing this study again after the development

of the square, the impact in terms of user increase can be determined more accurately. The surrounding hospitality could also determine a possible user increase through an elevated revenue.

These methods only measure the number of people that use the square, but these do not indicate the attractiveness in terms of appearance. This is subjective from person to person, but an overall positive attitude towards the appearance of the square would indicate a certain level of attractiveness. This can be determined through interviews or surveys with the different stakeholders. It is important to not only include the people visiting the square because they are probably biased towards a positive attitude than those who do not visit the square in the first place.

Meeting Spot

Defining a successful meeting spot is similar to a successful hotspot in the sense that it should attract people to the square. What differs is their reason to visit, the activities they perform, and the length of their stay. To use the square as a meeting spot, people use the square often, with a (larger) group of people, and for a longer period of time. The reason for them to visit is not to see the square but rather to use the functionality that the square provides in the form of a pleasant area to meet other people. The hotspot is mainly aimed at attracting tourists, but the meeting spot aims at providing a place for inhabitants to connect.

To determine whether this has been successful can again best be done by monitoring who uses the square and the purposes for which it is employed. This could be done through the same monitoring and surveying used to determine the success of the hotspot. If the square is used as a regular place to meet up by different groups of people, it can be considered a successful meeting spot.

Conclusion

Whether the redevelopment of Wilhelminaplein will be a success is something only time can tell. It is clear that the current version of the square does not reach the potential it could have. The necessity for change is high, so even the smallest interventions will have a big positive impact. The exact impact will be determined by which interventions will be chosen to be implemented, but every choice will be a great step towards a more liveable Punda.

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Appendix A

Summary: Transforming Urban Curaçao

The Sections A.1, A.2 and A.3 are based on Chapters 3, 4 and 5 from the UNOPS report *Transforming Urban Curaçao* [9] respectively. They are to summarize some of the key findings from each chapter.

A.1. Focus Areas

The report describes numeral focus areas in the cities of Barber, Montaña and Willemstad. Five of them are located in Punda. These focus areas are:

1. The various empty hotel buildings, like the Plaza Hotel building;
2. The Kuiperstraat, which has lost its historic character and liveability;
3. The alleys in the Inner-City that have been blocked by fences or gates;
4. The alleys in the Inner-City that are visually polluted by air-conditioning outlets;
5. Modern functional buildings that do not fit in with and break the character of the historic Inner-City.

A.2. Community-based Vision

The report mentions a community-based vision and an expert-based vision for the Urban areas of Curaçao. The relevant community ambitions for Punda are:

Bring people together in the context of socialising, entertainment, reflection, sports and recreation
Enjoy the colourful World Heritage buildings
Preserve nostalgic memories that testify to the culture and history of the Inner-City
Create open public spaces while **preserving** peace, culture and nature

The community wants the city to be people-oriented, accessible to anyone and more inclusive. The distribution of jobs, opportunities and services should be fair. To achieve this, objectives for 2030 have been formulated, with the most relevant ones for this research highlighted in red:

1. The city centre must be safe, vibrant, economically thriving and sustainable.
2. The people, especially the Curaçao ans, are central.
3. The city is climate-proof, with well-maintained buildings.
4. Punda is well connected to outer areas through a reliable, accessible public transport system.
5. Residents are involved in the decision-making process.
6. Government services are digitally accessible.
7. Services and other common buildings are accessible to everyone.
8. Everyone feels connected to a location on the island, having a 'sense of place'.
9. Wi-Fi is available in squares and meeting places in the neighbourhoods.
10. The necessary basic services are clustered at central key points with good connections.
11. New neighbourhood economy, small industries and ecotourism are encouraged.
12. Our coastal areas are protected, and our ecosystems are resistant to extreme weather.
13. We use as much as possible renewable energy sources.
14. Water is sustainably managed with a drainage system, wastewater collection and treatment.
15. Our natural assets are conserved and not removed.

A.3. Expert-based Vision

The experts share partly the same vision as the community. Added to that, they have a number of more technical requirements, including:

Controlling the decline of the population, by **increasing** housing opportunities and **enhancing** culture and economy.

Improving the accessibility by breaking physical and psychological barriers, by **improving** public transport reliability and **ensuring** the continuity and connectivity of the Inner-City.

Becoming more sustainable and resilient, by among others **decreasing** car dependence.

The physical barriers mentioned here refer to gated or blocked alleys. The psychological barriers are shown in Figure A.1. These are busy roads that pedestrians prefer not to cross.

The objectives formulated by the experts can be summarised as:

1. Punda will become the beating heart of the city again.
2. Punda is accessible through a public transport hub.
3. There are parking spots close to access points, so cars do not need to enter the city.
4. The Inner-City must be a pedestrian experience.
5. The walking experience must be improved through shading, green areas, protection from UHI, and scenery.

They also proposed some concrete ideas:

1. The transitional area between Punda and Pietermaai should be reshaped.
2. The Plasa Wilson 'Papa' Godett must be reconfigured
3. Pocket parks should be created in smaller areas like the Kuiperstraat
4. All closed and inaccessible alleys must be reopened.

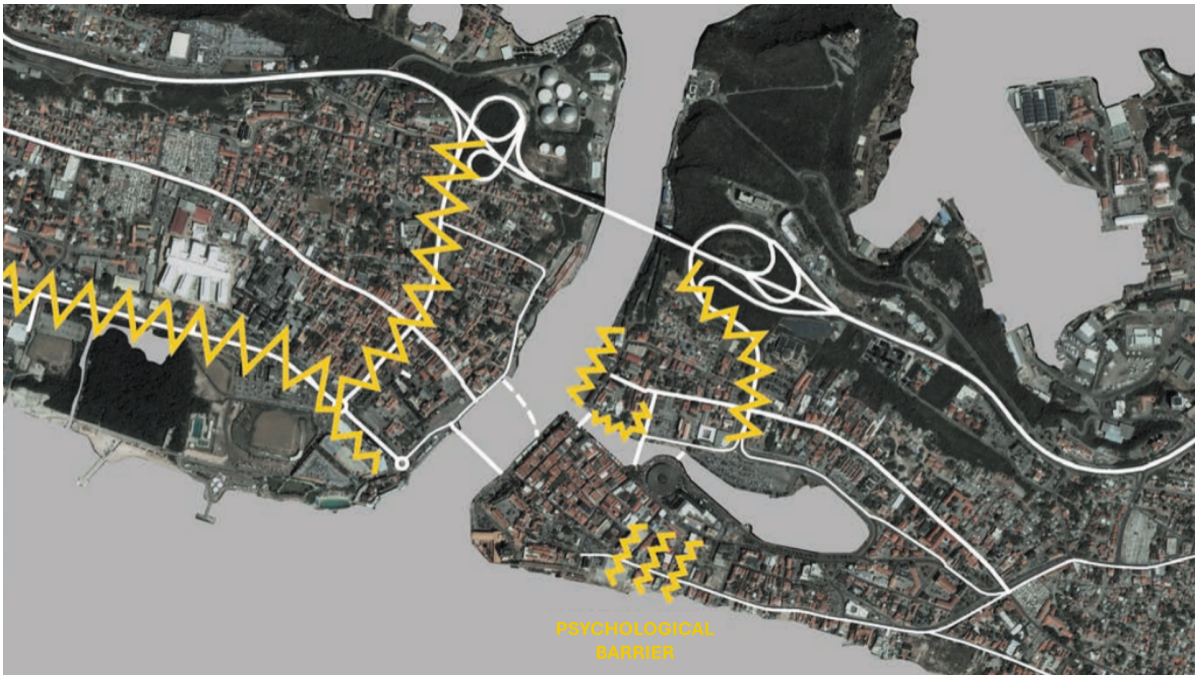


Figure A.1: Psychological barriers present in Willemstad [9]

In Figure A.2, the five focus areas mentioned above are highlighted.



Figure A.2: Five possible focus areas within Punda [53]

Appendix B

Measurement technique

Accurate measurements are crucial to gain information about the microclimates of streets in Punda. This chapter outlines the techniques used to capture temperature, wind speed, and surface temperatures in the urban environment. The data obtained from the METEO stations are compared with in-situ measurements. These measurements are also taken to gain insight into the effect of climate adaptation measures taken in other streets. Measurements are done for temperature and wind speed. Figure B.1 shows all locations in Punda at which measurements were taken.



Figure B.1: Map of measurement locations in Punda

The general measuring approach consists of 5-minute measurements for both wind and temperature in 10-second intervals. These were noted manually, as the equipment could not store data or provide averages over a measurement cycle.

B.1. Instruments

Atmospheric measurements for wind and temperature are performed with the EXTECH 45170CM [58] and EXTECH 42509 IR [57].

Wind speed (v) is measured by the EXTECH 45170CM [58]. It is measured in m/s and has an accuracy of 3 % below 20 m/s and 4 % above. The resolution is 0.1 m/s. The range of the sensor is 0.4-30.0 m/s. Air temperature is also measured with the EXTECH 45170CM in °C and has an accuracy of 1.2 °C. The resolution is 0.1 °C. The range of the sensor is 0.0-50.0 °C. No calibration of the sensor was possible.

The second sensor is EXTECH 42509 IR Thermometer with Color Alert [57]. It is a surface temperature sensor with an adjustable emissivity feature, making it possible to measure almost every surface. The surface temperature is measured in °C and has an accuracy of 2.5 °C for -2 °C to 94 °C. The resolution is 0.1 °C. The range of the sensor is -20 °C to 510 °C. No calibration could be done for this sensor.

B.2. Measurement Protocol

This section outlines the specific procedures for measuring wind speed, air temperature, and surface temperature. Since wind and air temperature measurements were conducted simultaneously, one protocol is provided for both.

Wind and Air Temperature Measurement Guidelines

Since the sensor lacks a function for recording averages, manual measurement readings were taken every 10 seconds over a 5-minute period. From this dataset, the average wind speed (in m/s) and air temperature (in °C) were calculated.

- Measuring at 1.5 meter height to minimise influence by excess ground heat and to reflect conditions felt by pedestrians [135], [136].
- Avoid direct sunlight in the sensor, by using an radiation shield [135], [136], [137].
- Avoid deposits or water retention on the sensor [136].
- Ensure good air flow → ”Face the Air Flow Sensor into the source of the air stream”[58], [136].
- Take notes of location (near AC, trees/cars/street furniture), surface materials, albedo and coordinates.
- Measure at least 1 meter, preferably 2 meters or more from walls or objects, as they influence the air temperature [138].
- Take the measurements in the middle of the street.
- The sky-view factor is determined at each location, with a special lens attached to our phone, at 1.1 meters height.
- Measurements are done at different moments of the day, but most of the measurements are done at the time that temperature is at its highest.
- The results are checked to see if they were not influenced too much by atmospheric conditions changing during the measurement.

Wind and Air Temperature Measurement Protocol

1. **Location Selection**: A representative location within the street was selected based on the guidelines, avoiding corners or spots exposed to abnormal wind or solar radiation. The selected location had to reflect the general street conditions.
2. **Documentation**: Pictures of the location were taken, including a sky-view factor image. Notes about the environment (cars, walls, street furniture) and the exact GPS coordinates were recorded.
3. **Preparation**: If direct sunlight was present, an umbrella was used to block the solar radiation from affecting the sensors.
4. **Sensor Activation**: The EXTECH 45170CM was activated and allowed to stabilise for 1 minute to adapt to the outdoor temperature.
5. **Measurement**: Wind speed and air temperature were noted every 10 seconds for 5 minutes. Data is stored in Xlsx-file.

6. **Deactivation**: After the measurement session, the sensor was deactivated and stored for future use.

Surface Temperature Measurement Guidelines

- The sensor is held 30 cm from the target, so the measured spot size will be 1 inch (2.5 cm) in diameter. This is the recommended distance for most measurements, as the sensor is calibrated to provide the most accurate temperature readings when the distance is such that the spot size matches the desired measurement area [57].
- The emissivity is adjusted to the value of the type of surface; see Table B.1. Emissivity values range from 0.1 for a very reflective object to 1.00 for a flat black finish. For most surfaces the emissivity can be set to 0.95, in Table B.1, the emissivities from the manual are stated [57].

Surface Temperature Measurement Protocol

Surface temperature measurements were conducted at the same location as wind and air temperature measurements to provide additional insights into local microclimatic conditions. Emissivity is adjusted for the correct material. Ground and wall surfaces were measured from a distance of 30 cm. After each measurement session, the sensor was deactivated and stored until the next measurement.

Table B.1: Emissivity of various materials [57]

Material under test	Emissivity
Asphalt	0.90 - 0.98
Concrete	0.94
Cement	0.96
Sand	0.90
Soil	0.92 - 0.96
Water	0.92 - 0.96

Data management: FAIR Principle

All measured data is stored in an Xlsx-file in accordance with the FAIR principle. All measurements are denoted with a location number, corresponding GPS coordinates, and time of measurement. Below, an example of a data entry is shown along with the column headers to give an idea of how the data is formatted.

Table B.2: Example of a measurement in the Xlsx-file, all data is stored in this format.

Date	Time	Geogr. lat.	Geogr. lon.	Timezone	Air temp. (°C)	VP (hPa)	v (m/s)
16/09/2024	14:48:00	12.105546	-68.933452	-4	34.8	31	1

Below is an overview how the collected data conforms to each letter of the FAIR acronym:

- F - Findable: Each location is marked with a location number and location name. An extensive overview of each location including pictures, GPS coordinates is given in a separate file. The weather conditions and special factors governing each measurement is also given in said file.
- A - Accessible: The data is stored in one Excel sheet with clearly defined columns. Information about what each column represents is given in the metadata file.
- I - Interoperable: All timestamps are saved in a HH:MM:SS format. The coordinates are stored consistently in the decimal degrees (DD) format.
- R - Reusable: All data is checked to not contain any errors. Coordinates are cross-referenced using QGIS and any potential outliers in the measurements are marked as such.

Measurement Time

Measurements are preferably done during the hottest part of the day, as the main goal of this study is to reduce the peak temperatures during the day. As only one sensor is used, temperatures are measured

between noon and 4 p.m. The temperatures measured by the METEO station in Punda are used as a reference to compare fluctuations of measurements by diurnal variations. The measurements are corrected to allow for a direct comparison. Multiple days of measurements are done in order to average out effects from isolated clouds and wind gusts.

B.3. Measurement Limitations

There were several limitations associated with the measurement process:

- **Sensor positioning**: the sensor is often not consistently placed into the main flow of the wind. The wind direction was sometimes variable. It is hard to place the sensor directly into the wind, and the wind direction is variable. To maintain consistency, the main wind direction at the start of the measurement was used, without readjusting the sensor during the session.
- **Low wind conditions**: it is debatable if there is still enough airflow through the sensor when there is no wind. It would be better to use a ventilator for these measurements, but then wind and temperature measurements should be separated. Separating wind and temperature measurements would lead to a longer measurement time, increasing the effects of the diurnal cycle.
- **Air-condition units**: AC units have a heating effect on the street. The differences in operational air-conditioning units varied by day, influencing the results.
- **Diurnal correction**: using the difference of the METEO station over the hours of measuring to correct diurnal effects could neglects unique microclimatic conditions in a street. Example are solar angle or wind conditions in this street.

Appendix C

PET Calculation Technique

The steps taken to calculate the Physical Equivalent Temperature (PET) with the RayMan model are described here [139] [140]. The RayMan model is a tool used to assess human thermal comfort by calculating the effects of radiation, meteorological data, and urban geometry. For this purpose, in-situ measurements are combined with meteorological data from METEO.

The first step is to calculate the PET per street. For each street, measurements were averaged so PET could be calculated, gaining insight into the heat perceived. Temperature and wind measurements on street level are combined with data from the METEO station in Punda. This station is located at the *Douane* building in Punda, see Figure B.1. METEO data for air temperature, relative humidity, wind speed and rainfall were gathered. The air temperature data is used to correct for diurnal variation. Relative humidity is used to calculate vapour pressure. Finally, as can be seen in the METEO data, there was no precipitation during the measurements.

The second step is calculating PET reductions at Wilhelminaplein for the proposed interventions. For this purpose, a hot day was chosen. This enables us to find extreme values for PET and to see how to maximize mitigation. This strategy was chosen, however, to see the worst-case scenario and know that things can probably only get better in practice. All measurements for Wilhelminaplein are combined, as it is assumed that air temperature does not vary much on a small scale.

The PET on Wilhelminaplein for the proposed interventions is calculated by changing the parameters, explained below, from their initial setting to the setting corresponding to the analysed intervention. Parameters that will be changed are the Bowen ratio, the Albedo of the surroundings and the sky-view factor. The Bowen ratio is changed to account for a change in vegetation cover per intervention. The Albedo of the surroundings is changed if the surface or objects in the lower hemisphere are changed. The lower hemisphere is below 1.1 m and the upper hemisphere is above 1.1 m, see C.1. The sky-view factor accounts for the upper hemisphere and is changed if shadows are created or if materials of current objects are changed.

For RayMan, several inputs are needed. All inputs are described in the following sections.

C.1. RayMan Methods

The formula that RayMan uses is as follows [141]:

$$M + Wo + R + C + E_{sk} + E_{res} + E_{sw} + S = 0 \tag{C.1}$$

Here, the variables are:

- M: Metabolic heat production
- Wo: Mechanical work
- R: Fluxes of radiation
- C: Sensible heat
- E: Latent heat fluxes via skin, respiration and sweating:
- S: Storage is assumed to be 0.

All variables are given in Watts (W) and are influenced by the input parameters explained below.

First, RayMan determines the energy balance for the actual input environment. Then, it does the same for a virtual environment as proposed by Höppe [20]. The virtual environment is a 'typical indoor

setting' with a wind speed of 0.1 m/s and a water vapour pressure of 12 hPa. In this environment, RayMan uses an iterative approach to determine the (apparent) air temperature T_a for which the effect on the human energy balance is the same as for the actual environment. This new T_a equals PET.

Air temperature

To calculate PET, air temperature data is used. These are performed in-situ. Appendix B describers the measurement protocol for the air temperature measurements. Measurements were taken over a span of 5 minutes at 10-second intervals. To compare these measurements, corrections need to be made to account for diurnal variation. For this, reference measurements of the METEO station in Punda were used.

This was done in several steps.

1. Convert METEO hour averages to minute averages by interpolation.
2. As the METEO values are hour averages, assume that this value is reached at 30 minutes past the hour. Adjust the time range for this by half an hour.
3. Assume the highest temperatures occur between 12:30 and 15:30. Thus, the reference time in the middle is 14:00.
4. To account for short-time fluctuations, take the average air temperature of the three hours around the measurement, so the temperatures between 1.5 hours before and 1.5 hours after the measurement was taken. Do this for both the measurement times as well as the reference times.
5. Correct the measurements according to Equation C.2.

$$T_{\text{corrected}} = T_{\text{measurement, t}} + T_{\text{METEO, 14}} - T_{\text{METEO, t}} \tag{C.2}$$

- $T_{\text{corrected}}$: Temperature measurement corrected for diurnal variation.
- $T_{\text{measurement, t}}$: Measurement at time t.
- $T_{\text{METEO, 14}}$: 3-hour average air temperature around 14:00 for METEO station Punda.
- $T_{\text{METEO, t}}$: 3-hour average air temperature around time t for METEO station Punda.

Vapour pressure

The METEO data contains hourly average relative humidity values. Although this is the commonly used variable to describe the amount of water the air holds, it is not practical for the model. It is heavily time-dependent, as it is directly related to air temperature, which is very variable. To get rid of time dependence, the vapour pressure was calculated according to Equations C.3 and C.4. Vapour pressure, or the total amount of water in the air, is assumed constant for the small period of time considered in the model.

$$RH = \frac{e'}{e'w} \cdot 100\%, \text{ the ratio between vapour pressure e' and saturation VP e'w} \tag{C.3}$$

$$e'w = 6.11 \cdot e^{17.27T_a/(237.3+T_a)} \tag{C.4}$$

Vapour pressure is also assumed to be spatially constant on a small scale like Wilhelminaplein [142], meaning that the air contains a more or less homogeneous mass of water per unit of volume. Because of its ease of use, the data file given to RayMan as input contains a column with vapour pressures. The model then uses these constant values to redetermine the relative humidity for its PET calculations on a different time resolution.

Cloud coverage

METEO calculates cloud coverage for every hour. It is measured in oktas, see list below for further explanation [143].

- 0 oktas represents the complete absence of cloud
- 1 okta represents a cloud amount of 1 eighth or less, but not zero
- 7 oktas represents a cloud amount of 7 eighths or more, but not full cloud cover
- 8 oktas represents full cloud cover with no breaks

- 9 oktas represents sky obscured by fog or other meteorological phenomena

Cloud coverage (cc) is used with time, date and geographic location to calculate the amount of global radiation. global radiation is divided between direct solar irradiation (I) and diffuse shortwave irradiation (D). Depending on the cloud coverage, solar zenith angle φ, Linke turbidity T_L, relative optical air mass r_{opt} and atmospheric pressure δ_{opt}, the division between Direct and Diffuse changes. Direct radiation dominates under clear skies (low cc), low turbidity, and small solar zenith angles, while diffuse radiation becomes more significant under cloudy skies (high cc), high turbidity, large solar zenith angles, and high relative optical air masses.

Wind speed

Wind speed measurements were taken simultaneously with the air temperature measurements by the sonic anemometer. All wind speeds correspond to the air flow in the direction of the streets in which they were measured. In the case of open terrain, like Wilhelminaplein and Waterfort, the device was oriented in the general wind direction.

Because the RayMan model can yield unrealistic results of PET with low wind speeds in combination with input obstacles, the lower limit for wind speed was chosen to be 1 m/s in these cases. So even when measurements show lower average wind speeds, it is set to 1 m/s. For the case of Wilhelminaplein, this is not a bad assumption.

Surface temperature

Surface temperatures (T_s) were measured at the different locations; in Appendix B, the protocol for this measurement is explained. The surface temperature can be used to calculate the longwave radiation of the lower hemisphere. This means all radiation coming from walls below 1.1 meters and from the surface is accounting in the lower hemisphere [140]. See Figure C.1 for a diagram, in which the hemispheres are divided by a horizontal red line at 1.1 m height.

Inputting T_s into the model can make it more accurate. However, RayMan is also able to calculate surface temperatures by itself. The advantage of this, is that in a new situation, e.g. shading over a surface, no assumptions need to be made. RayMan can calculate a new surface temperature based on the radiation balance. The measured temperatures are therefore used to verify RayMan outputs.

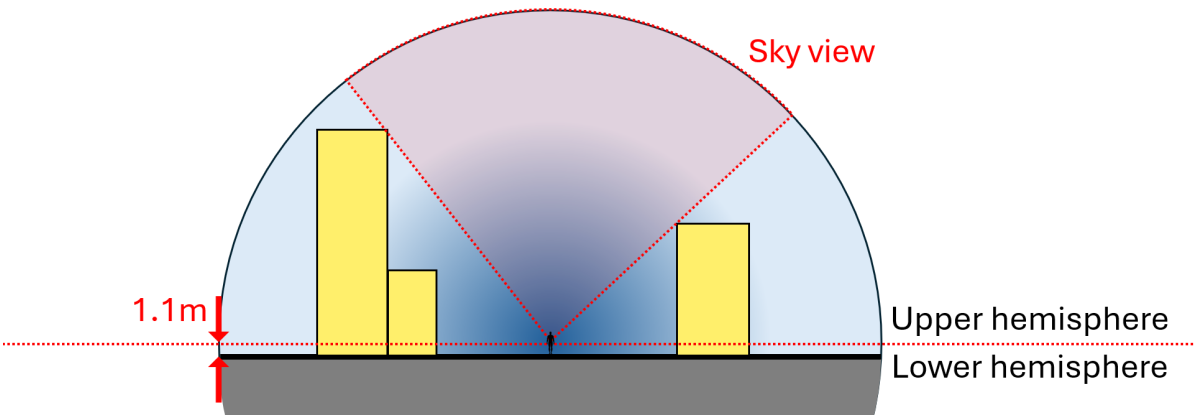


Figure C.1: Overview of hemispheres and skyview

Personal data

For PET calculations, a sample person is considered by RayMan. The usual personal characteristics are a man with a height of 1.75 m and a weight of 75 kg.

Albedo of human being

The standard albedo of human skin of 0.3 used in RayMan does not apply to the typical Curaçaoan, as albedo depends on skin colour. The albedo of darker skin is closer to 0.1 [144] [145].

Clothing and activity

As for the personal data, clothing and activity are not modified from the usual values, which are 0.9 clo for clothing and 80 W for activity in a standing position.

On the clothing scale, 0 clo means no clothing, 1 clo means a business suit, and $\gg 1$ clo would be winter clothing. The typical (male) clothing in Curaçao consists of long pants and a shirt. 0.9 clo is, therefore, a realistic estimation.

Bowen ratio

The Bowen ratio (β) is the ratio of sensible heat flux to latent heat flux, see Equation C.5. It is needed to calculate the effect of sensible heat of surfaces and latent heat by evaporation. Typical values are $\beta = 0.1$ for oceans and $\beta = 5.8$ for desert-semidesert areas [146]. Areas with little vegetation and low water availability have a higher Bowen ratio than areas with more vegetation and high water availability [147] [148] [149].

For this study, the Bowen ratio needs to be determined per street. For a street with no vegetation, the Bowen ratio could go up to 10, depending on the difference between surface and air temperature, vapour pressure deficit, effective precipitation and soil water content [150], [151], [152]. With 35-75 % amount of green space next to pavement the Bowen ratio is between 0.5 and 2.5 with generic class mean 1. With 25-40 % amount of green space next to pavement the Bowen ratio is between 1.5 and 3 with generic class mean 2. With less than 20 % green, the Bowen ratio is between 3 and 8, with generic class mean 4 [147].

For this study, the data is expanded to values for every 5 or 10 % green space; see Table C.1. Values are chosen higher than the mean due to the low water availability at Curaçao in September. This Table is used to determine the Bowen ratio for every location. The green percentage is calculated for a radius of 10 meters around the location. If a street is too small, the radius in that direction is adjusted.

Trees can evaporate more water than grass in dry conditions [153], [154]. The latent heat flux for trees is, therefore, higher than that of grass for the same percentage of green space. So, with an equal green space percentage, the Bowen ratio is higher for grass. Grass areas are therefore accounted for with a factor of 0.5.

$$\beta = \frac{Q_h}{Q_e}, \text{ where } Q_h \text{ is sensible heating and } Q_e \text{ is latent heating.} \tag{C.5}$$

Table C.1: Bowen ratios assumed in this study for a percentage of green around the location

Amount of Green Space	Bowen ratio
100 %	0.2
90 %	0.4
80 %	0.6
70 %	0.8
60 %	1.0
50 %	1.3
40 %	1.8
35 %	2.1
30 %	2.4
25 %	2.7
20 %	3
15 %	4
10 %	5
5 %	6.5
0 %	8

Albedo of surroundings

For the albedo of the surroundings, the lower hemisphere of the person is taken. As the sky-view factor is taken at 1.1 m height, this means the lower hemisphere is everything below 1.1 m. In Table C.2, some values are given for the albedos of typical building materials used in pavement.

Table C.2: Albedo of various materials [155], [111], [147], [156], [157], [158], [159]

Material	Albedo	Emissivity
Granite	0.5	0.96
Limestone	0.7	0.93
Marble	0.8	0.95
Basalt	0.4	0.90
Concrete	0.1-0.5	0.85-0.97
Brick	0.2-0.4	0.90-0.95
Asphalt	0.05-0.27	0.89-0.96
Soil (Dark colour, dry)	0.10-0.13	0.89-0.93
Soil (Light colour, dry)	0.18-0.30	0.91-0.95
Low vegetation	0.16-0.26	0.90-0.98
Deciduous Forests	0.13-0.20	0.90-0.99
White paint, smooth	0.7-0.9	0.85-0.95
White wash paint	0.6-0.8	0.85-0.95
Red, brown, green paint	0.2-0.35	0.85-0.95
Dark brown, dark blue	0.2-0.3	0.80-0.95
Black paint	0.02-0.15	0.90-0.98

For each location, an albedo is estimated based on this table and its surroundings (pavement and nearby objects/walls).

Sky-view factor

For the upper hemisphere, another method is used, as sky-view factor (SVF) images can be uploaded in the RayMan model. The SVF is the fraction of the visible sky in 3D. In Figure C.1, a 2D example is given. It is dimensionless and ranges from 0 to 1, where 0 means that the sky is totally covered by terrain or obstacles, while 1 stands for a free sky. To calculate the SVF, fish eye images of the upper hemisphere are implemented in the model. Fish eye images are shot with a mobile phone with a fish eye lens on it. The pictures are shot at 1.1 m height. Rayman uses a weighting factor to adjust the impact of a pixel by the sine of the zenith angle [141]. In the model, a division is made between free sky, buildings and trees. The albedo and emissivity per building and tree are manually set in the model. The values used in Table C.2 are used to estimate the correct values for every part of the sky-view factor image.

Lower limit of relative humidity for diffuse radiation

This is the value for which the model assumes fog conditions, or a visibility of less than 1 km. Then, all radiation is considered diffuse. The standard value is 90 %. Curaçao, however, can reach higher relative humidities without fog. That is because the wind rarely reaches speeds low enough for fog formation. From the METEO data, an example was found on September 1, where a relative humidity of 96 % was reached. Still, the minimum visibility on that day was 4 km, and at the time of the highest humidity, it was in the range of 25 km. For this reason, the lower limit is set to 99 %, although it should not matter in our case, as the relative humidity does not exceed 90 % during our measurements or, in general, during the highest day temperatures.

Other parameters

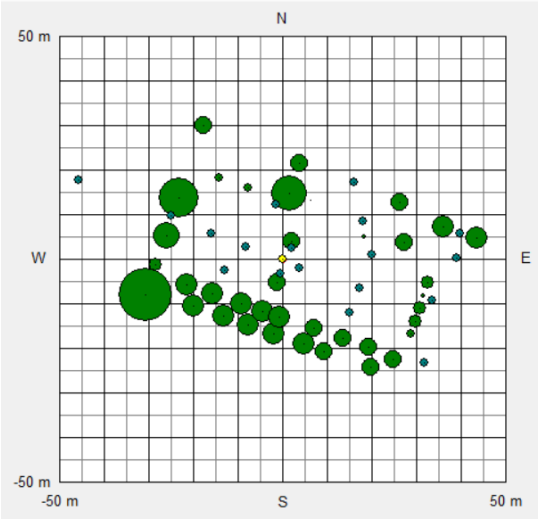
All other optional parameters that RayMan can take as input are automatically calculated by the program.

Obstacles

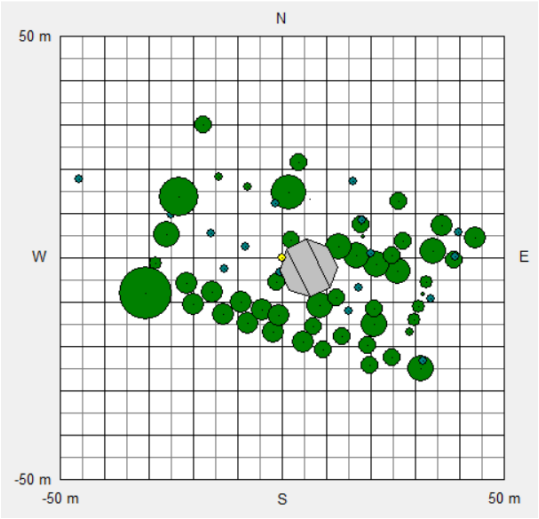
Together with the variables and sky-view factor photos, so-called obstacle files are implemented in the model. In these files, trees can be placed in their desired locations, so the model can take them into account regarding evapotranspiration and shading. This is especially advantageous when implementing interventions. Obstacles are used in combination with sky-view factor photos, not as a replacement. The obstacle layouts for interventions 0-3 are shown in Figure C.3.



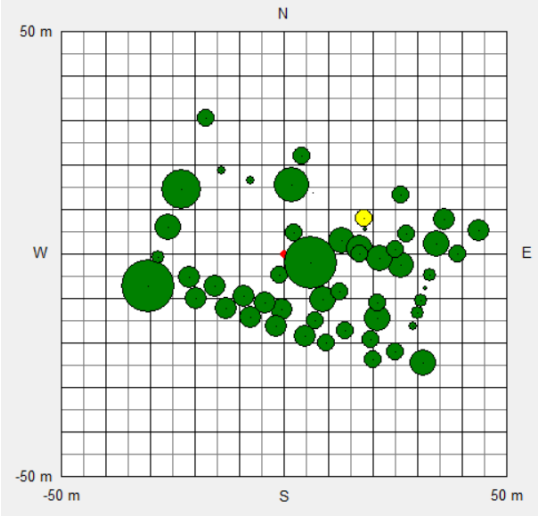
Figure C.2: Map of modelled locations on Wilhelminaplein



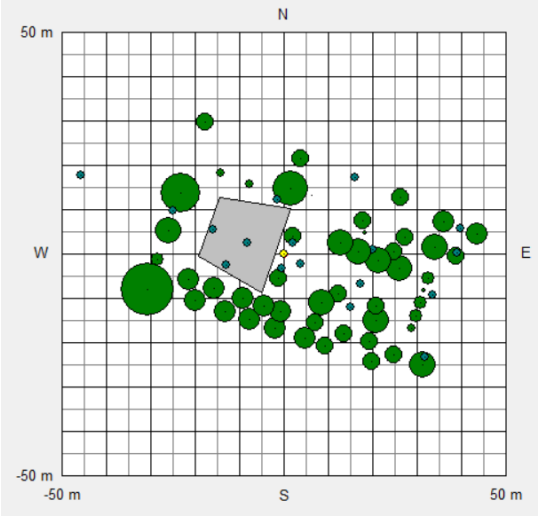
a) Obstacles for the current state of the square



b) Obstacles layout for the intervention with misting system



c) Obstacles layout for the intervention with the centrepiece tree



d) Obstacles layout for the intervention with shading canvas

Figure C.3: Obstacles for interventions 0-3. The small teal dots are the locations for which the PET was calculated. See Figure C.2

C.2. Limitations RayMan Model

- RayMan does not consider the reflection of radiation off of vertical objects [140].
- Lower hemisphere <1.1 m is assumed as a uniform temperature, but both ground and lower walls have influence and probably different material types.
- RayMan is very sensitive to wind speed, meaning that wind speeds under 1 m/s yield unrealistic PET values.
- RayMan does not take into account the reduction of wind speeds due to obstructions.
- Surface temperatures are calculated without material properties of the surroundings other than albedo, meaning that heat storage is not considered.
- Obstacles added in RayMan, such as trees, do not accurately represent real-life objects.
- When too close to an added tree in RayMan, i.e. a tree present in the obstacle file, the effect of the tree on shading is not properly covered in the model.

C.3. Recommendations

- Multiple measurements at the same time for a longer time period, so time variations are filtered out.
- Use pyranometers and pyrgeometers for both direct and diffuse solar radiation measurements, for more accurate calculation of the radiation balance in RayMan.
- Measure for multiple days to see the diurnal variation.
- Determine PET for different moments throughout a whole year and their corresponding thermal comfort classes to quantify the time gained that people are willing to spend at the square.
- Use a more advanced hemispherical photograph, as the fish-eye lens in this study did not capture the full 180 °.
- Measure at different locations simultaneously with similar equipment to compare locations.

Appendix D

Measurement Results

D.1. Measurements for Punda

The measurements for air temperature T_a and wind speed v are summarized in Table D.1. Vapour pressure VP is taken from the METEO data. For the calculations, a cloud cover (cc) of 0 octas was taken for each location. Lastly, for each location, the albedo α and Bowen ratio β were determined.

Table D.1: Input data for Punda locations

Location	T_a **(°C)**	**VP (hPa)**	**v (m/s)**	**cc (octas)**	α **(-)**	β **(-)**
Gomez plein 1	34.9	31.0	0.36	0	0.3	2.1
Kuiperstraat 1	34.4	31.1	1.6	0	0.25	8
Kuiperstraat 2	34.6	31.1	0.46	0	0.25	8
Kuiperstraat 3	33.7	31.1	2.9	0	0.25	8
Passaatstraat 1	33.6	31.6	2.4	0	0.3	3
Passaatstraat 2	34.0	31.6	0.90	0	0.3	3
Rifwaterstraat 1	35.5	31.9	0.58	0	0.35	8
Sebastopolstraat 1	34.7	32.4	0.34	0	0.35	8
Waterfort 1	32.4	31.5	1.5	0	0.35	8
Wilhelminaplein 1	35.7	31.6	0.73	0	0.25	8
Wilhelminaplein 2	35.3	32.2	0.45	0	0.25	2.1
Wilhelminaplein 3	32.9	32.5	2.0	0	0.25	6.5
Wilhelminaplein 4	33.0	31.5	1.5	0	0.3	3
Wilhelminaplein 5	34.0	33.0	1.3	0	0.25	8
Windstraat 1	35.1	32.7	0.67	0	0.3	8
Windstraat 2	33.3	31.6	2.7	0	0.3	8
Windstraat AC 1	35.8	30.3	0.38	0	0.3	8
Windstraat AC 2	35.0	30.3	0.68	0	0.3	8
Windstraat AC 3	34.4	30.3	0.74	0	0.3	8

D.2. General measurements Wilhelminaplein

Table D.2 gives the RayMan input values that were the same for each location on Wilhelminaplein. The calculation of the PET for every intervention has been done with these inputs. So the measurements are only used in determining the development site. The RayMan input values include five moments in time on a specific date, September 1^{st} 2024. The latitude, longitude and elevation are practically the same for all locations. The time zone at the time of measuring was UTC-4. Based on the measurements for T_a and the data from METEO, extreme values for air temperature at those times were estimated. The same was done for wind speed v and vapour pressure VP. For VP, only METEO data was used.

For later calculations, average values for T_a and VP were used, contrary to the extreme values. These were calculated from the METEO data at each time of the day, see Table D.3.

Table D.2: General input data for all locations on Wilhelminaplein

Date	Time	Lon (°E)	Lat (°N)	z (m)	UTC+h	T_a (°C)	VP (hPa)	v (m/s)	cc
1.9.2024	12:00	-68.9334	12.1042	0	-4	35	35	1	0
1.9.2024	13:00	-68.9334	12.1042	0	-4	36	35	1	0
1.9.2024	14:00	-68.9334	12.1042	0	-4	36	35	1	0
1.9.2024	15:00	-68.9334	12.1042	0	-4	36	35	1	0
1.9.2024	16:00	-68.9334	12.1042	0	-4	35	35	1	0

Table D.3: General input data for all locations on Wilhelminaplein

Date	Time	Lon (°E)	Lat (°N)	z (m)	UTC+h	T_a (°C)	VP (hPa)	v (m/s)	cc
1.9.2024	12:00	-68.9334	12.1042	0	-4	32.5	33.9	1	0
1.9.2024	13:00	-68.9334	12.1042	0	-4	32.5	33.7	1	0
1.9.2024	14:00	-68.9334	12.1042	0	-4	32.6	33.1	1	0
1.9.2024	15:00	-68.9334	12.1042	0	-4	32.7	32.1	1	0
1.9.2024	16:00	-68.9334	12.1042	0	-4	32.4	31.3	1	0

D.3. Location specific data Wilhelminaplein

The only parameters that varied per intervention in the input data file were the Albedos and Bowen ratios. The sky-view factor is also changed in RayMan for every intervention. Here, the Albedos and Bowen ratios are the same for interventions 1, 3 and 4. Table D.4 gives the overview for these values. These values are determined with C. The interventions are stated below:

0. The current situation
1. The intervention with the misting machine
2. The intervention with the big tree
3. The intervention with the big shading
4. The Quick Wins

Table D.4: Albedo α and Bowen ratio β per location and intervention

Location	α_0 (-)	β_0 (-)	$\alpha_{1,3,4}$ (-)	$\beta_{1,3,4}$ (-)	α_2 (-)	β_2 (-)
A	0.35	6.5	0.35	3.0	0.35	3.0
B	0.30	5.0	0.20	1.8	0.20	1.8
C	0.20	6.5	0.20	2.1	0.20	2.1
D	0.30	4.0	0.20	1.8	0.20	1.8
E	0.30	2.4	0.30	2.4	0.30	2.4
F	0.25	5.0	0.25	1.0	0.25	0.8
G	0.30	3.0	0.30	2.4	0.30	1.3
H	0.25	8.0	0.25	2.1	0.25	8.0
I	0.25	2.1	0.20	1.3	0.20	1.3
J	0.35	8.0	0.35	8.0	0.35	8.0
K	0.35	5.0	0.35	5.0	0.35	5.0
L	0.30	4.0	0.30	4.0	0.30	1.8
M	0.25	6.5	0.25	1.8	0.25	0.6
N	0.25	8.0	0.35	1.0	0.35	0.4
O	0.25	2.7	0.25	1.8	0.25	1.8
P	0.30	3.0	0.30	3.0	0.30	1.8
Q	0.30	3.0	0.30	2.7	0.30	2.7
R	0.25	3.0	0.25	1.0	0.25	0.8
S	0.30	6.5	0.30	2.4	0.30	2.4

D.4. Discussion of Measurements

As explained more in-depth in Appendix B, the measurements were conducted under extreme circumstances, with limited time and equipment. From the results, no definitive conclusions can be drawn, other than to compare similar locations during similar circumstances. The main goal of these measurements was to get an understanding of how the microclimates in the city relate to each other.

Air temperatures could be corrected according to Equation C.2, but that was not possible for wind speeds. These are still heavily time-dependent, so they are a source of variability.

Appendix E

PET Calculation Results

In this appendix, the results from the RayMan calculations are summarized. The interventions are numbered as follows:

0. The current situation (red)
1. The intervention with the misting machine (blue)
2. The intervention with the big tree (green)
3. The intervention with the big shading (magenta)
4. The Quick Wins (lime)
5. The Quick Wins with average meteorological conditions (grey, only mentioned in E.5)

Generally, if not all lines seem to be present in the graph, they are underneath the lime line. This is, because the calculated PETs are identical for these situations and due to the plotting technique, where lines are plotted over each other.

Location B is excluded from the graphs, as for this point, the model consistently returned unrealistic values.

It is important to note that all calculated PETs are really high. This is due to the decision to take an extreme case in the hottest month of the year. This decision has been accounted for somewhat in E.5. To further understand the resulting values, they are compared to the comfort temperature scale. In Table E.1, typical PET perception descriptions are given. Here, comfort temperatures lie between 18 °C and 23 °C [21]. This is, however, for a European case. Various studies show that comfort temperatures in tropical regions lie much higher, with a neutral range up to around 30 °C [22] [23].

Table E.1: Thermal Perception and Physical Stress by PET (°C) [21]

PET (°C)	Thermal Perception	Grade of Physical Stress
> 41	Very hot	Extreme heat stress
35 – 41	Hot	Strong heat stress
29 – 35	Warm	Moderate heat stress
23 – 29	Slightly warm	Slight heat stress
18 – 23	Comfortable	No thermal stress

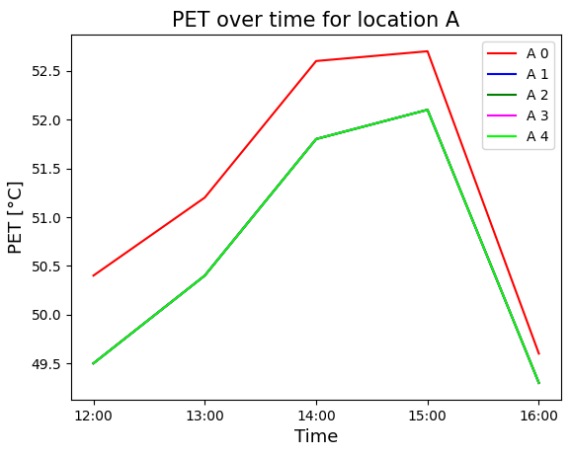
Based on the Table and comfort temperatures from literature, the thermal perceptions will likely shift 6-9 °C. This means that the following Table G.1 is assumed for drawing conclusions:

Table E.2: New Thermal Perception and Physical Stress by PET (°C)

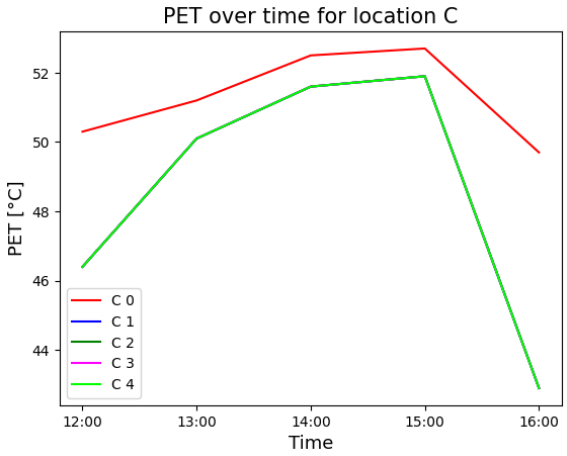
PET (°C)	Thermal Perception	Grade of Physical Stress
> 50	Very hot	Extreme heat stress
42 – 50	Hot	Strong heat stress
35 – 42	Warm	Moderate heat stress
30 – 35	Slightly warm	Slight heat stress
25 – 30	Comfortable	No thermal stress

E.1. PET over Time

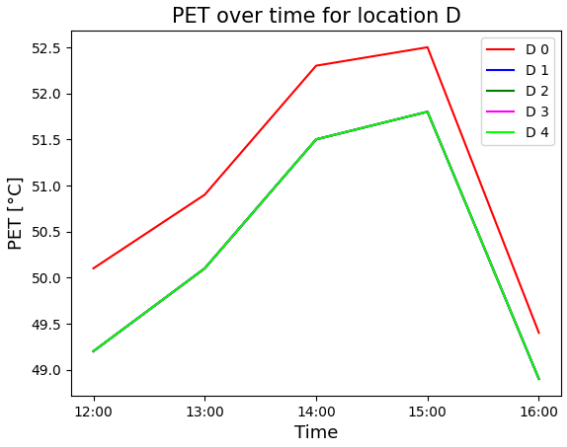
The results of the PET calculations over time can be found in Figure E.1A to E.1S:



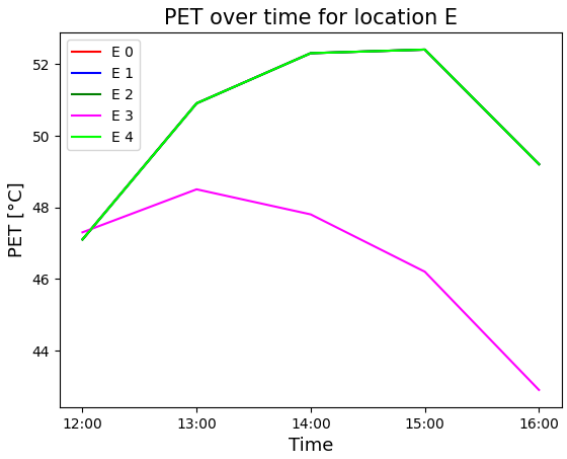
E.1A



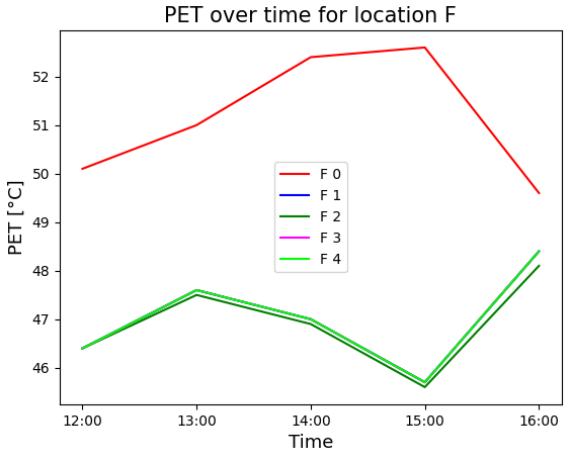
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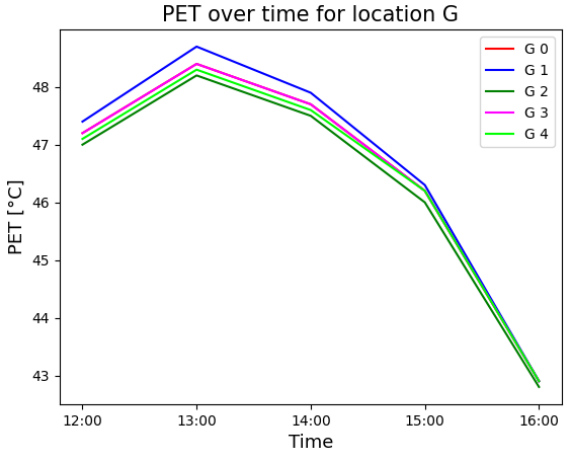
E.1D



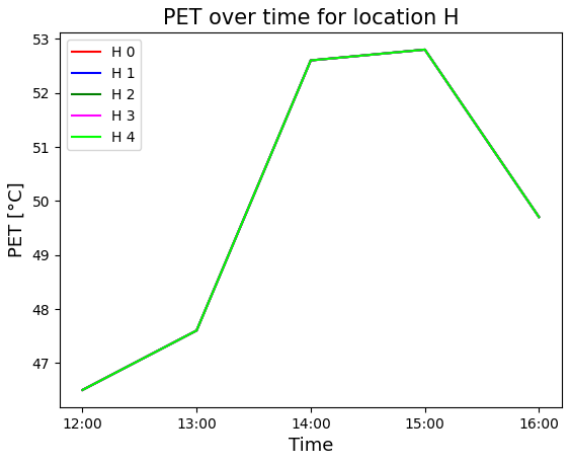
E.1E



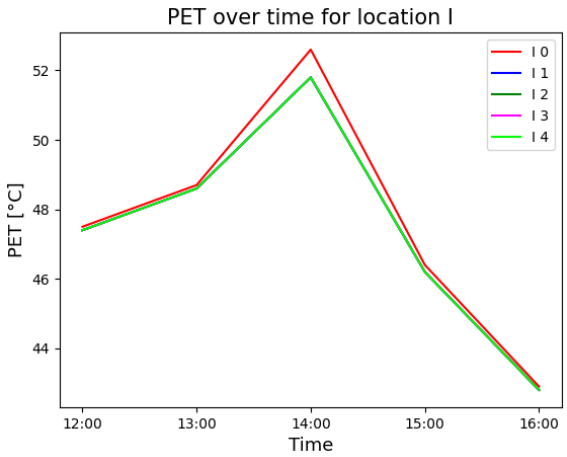
E.1F



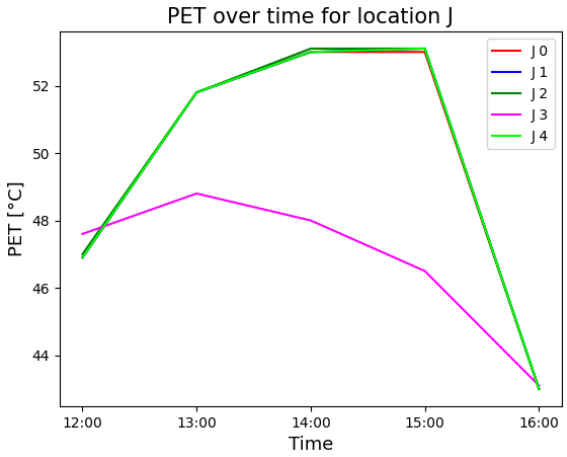
E.1G



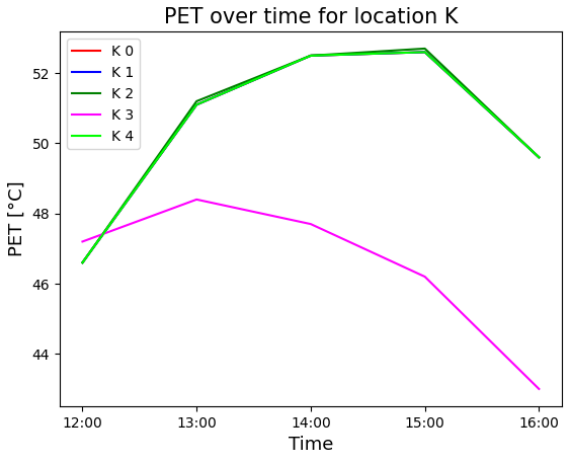
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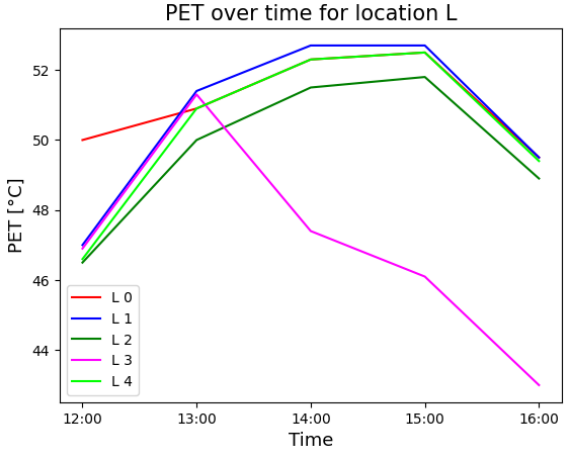
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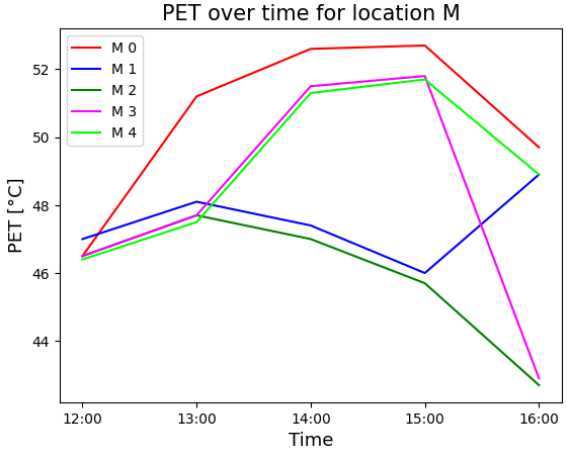
E.1J



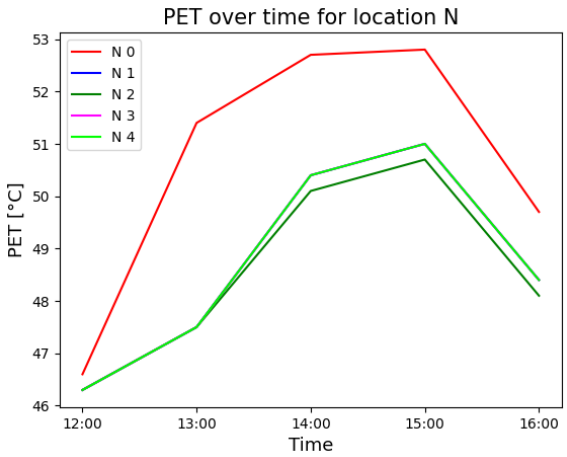
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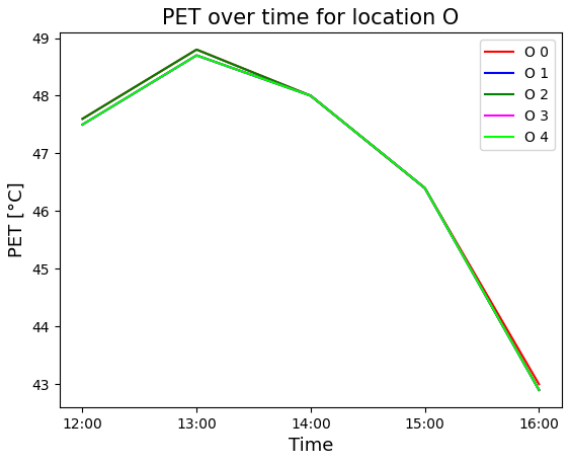
E.1L



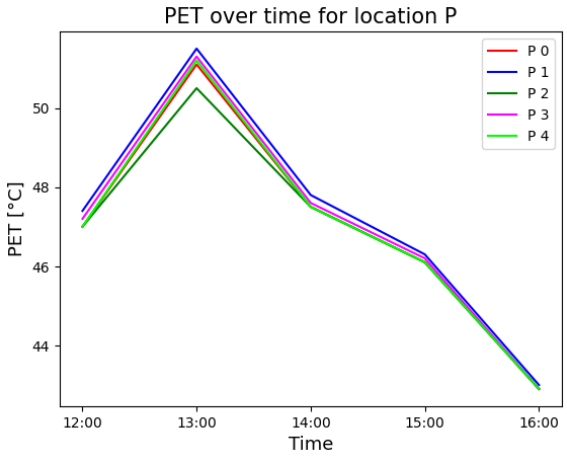
E.1M



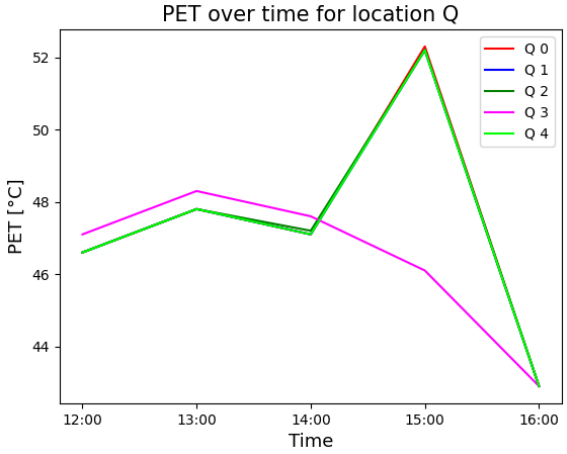
E.1N



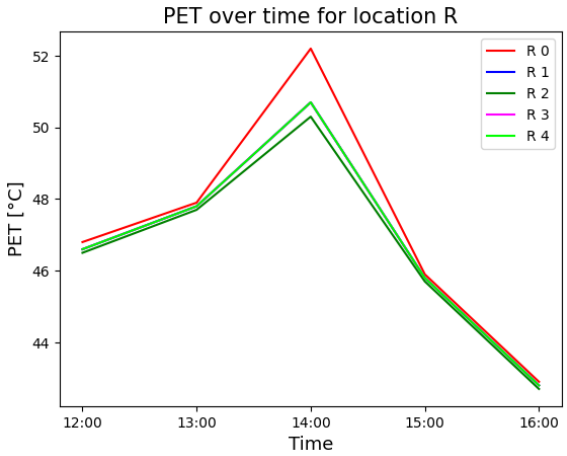
E.1O



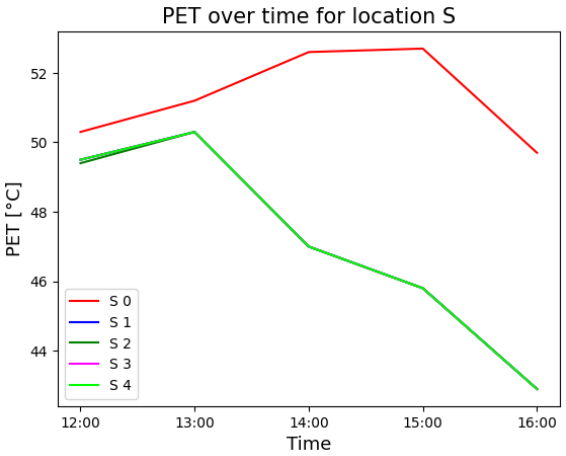
E.1P



E.1Q



E.1R



E.1S

Figure E.1: PET over time for all locations

E.2. Mean PET

As can be seen in the graphs in Figure E.1, the interventions have varying effect on the PET. To roughly compare the interventions with each other, the mean PETs per location are plotted in one overview in Figure E.2

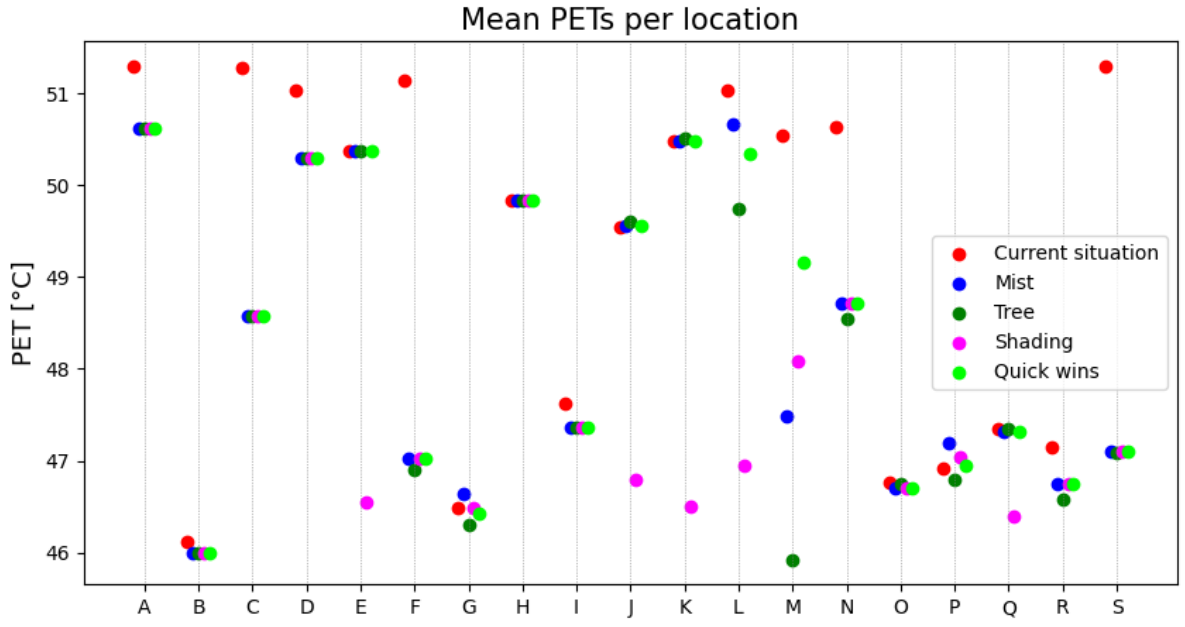
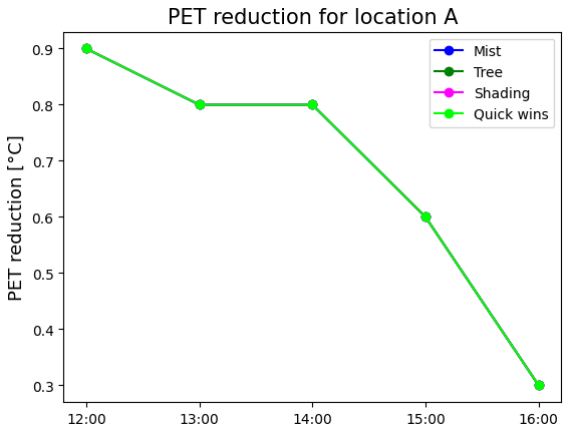


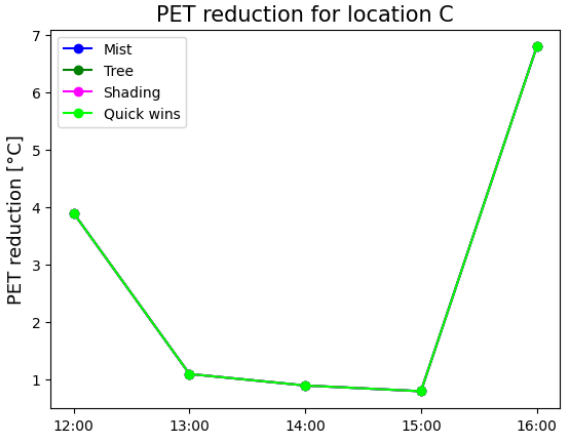
Figure E.2: Mean PET for each location and intervention

E.3. PET Reduction

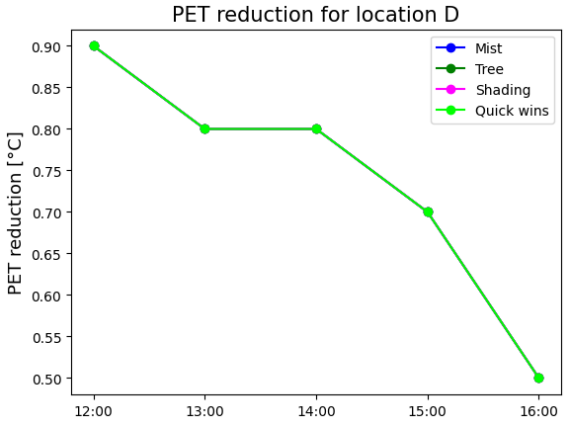
Figures E.5A to E.5S show the reduction in PET per location. Here, a positive value means a PET decrease at the corresponding time.



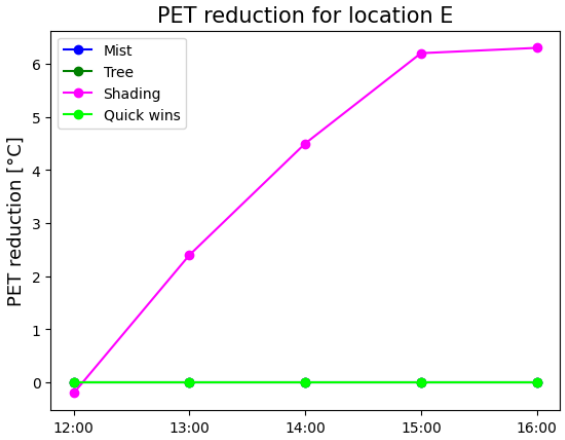
E.5A



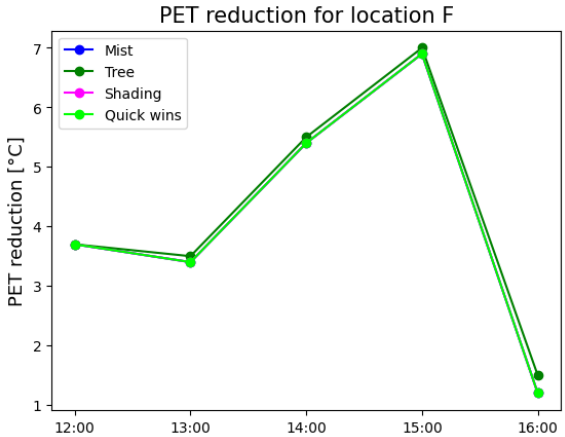
E.5C



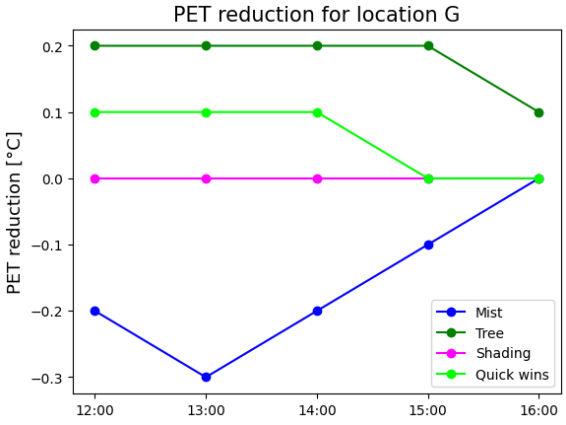
E.5D



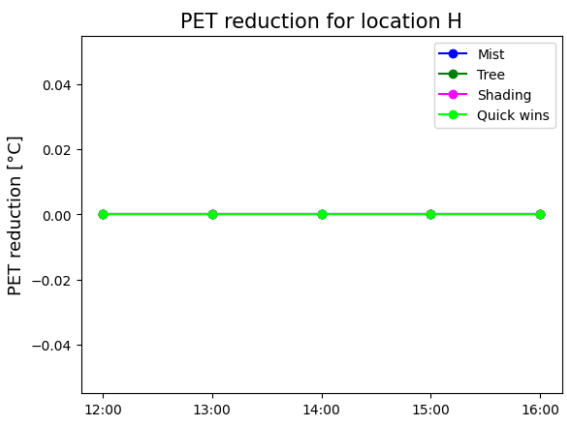
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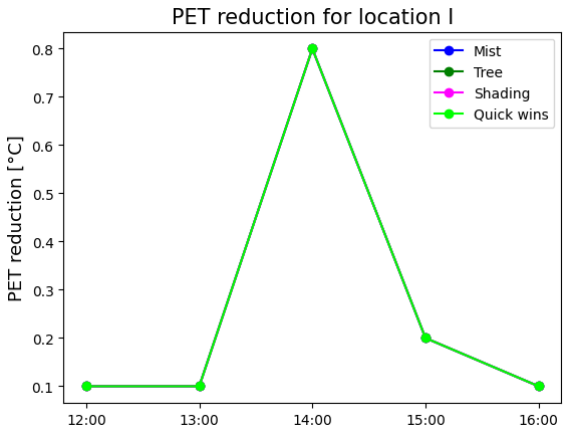
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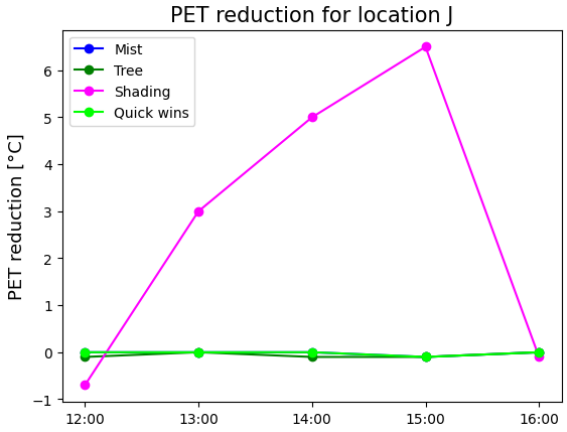
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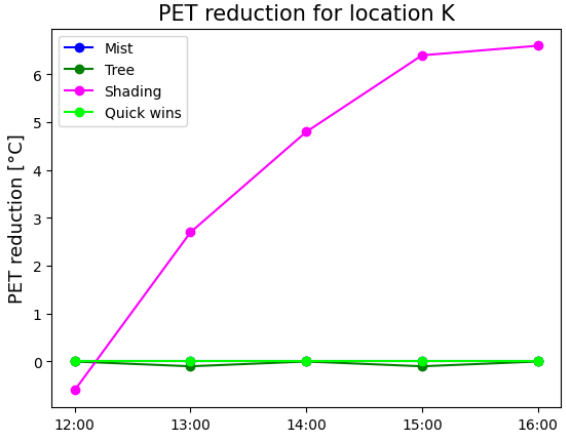
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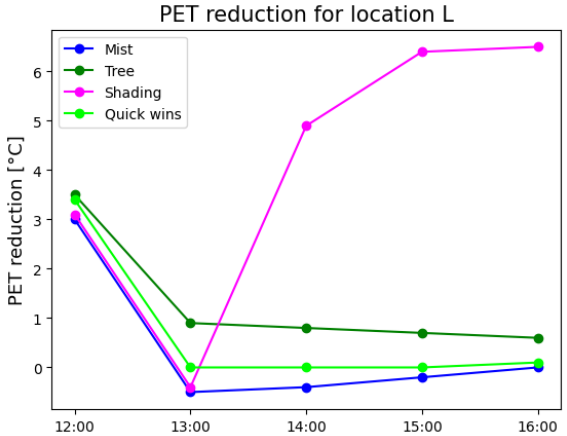
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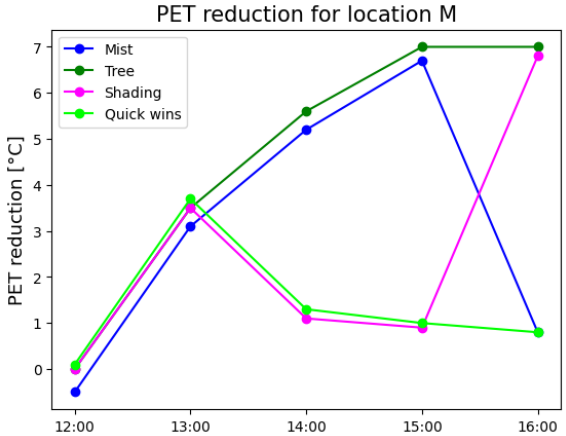
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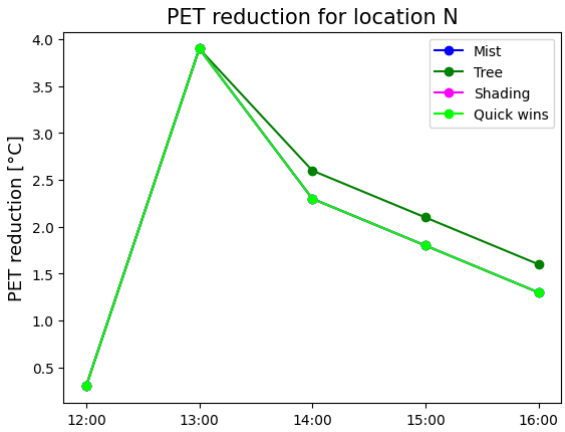
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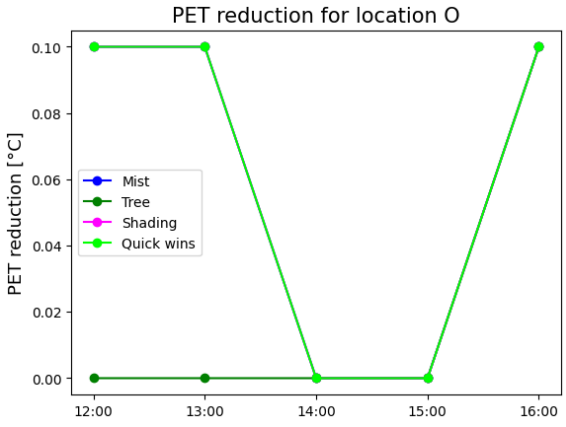
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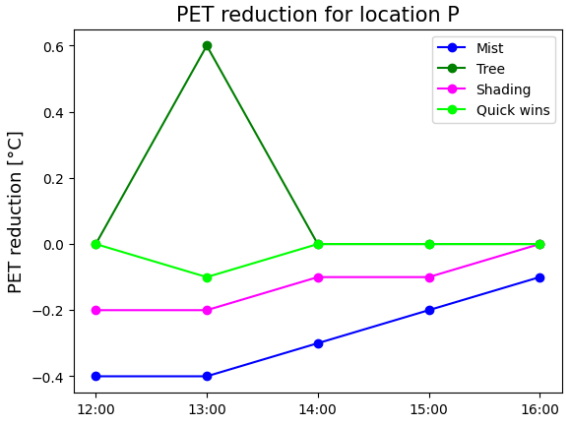
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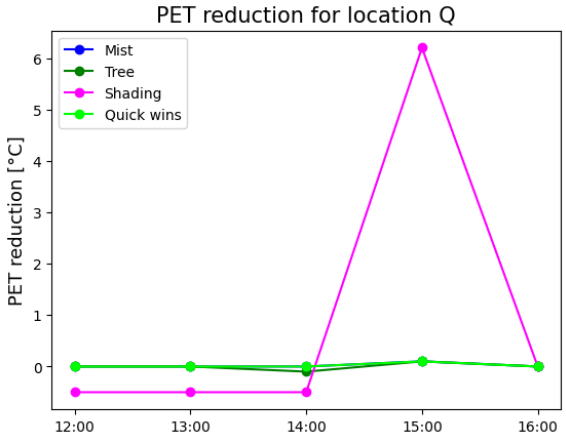
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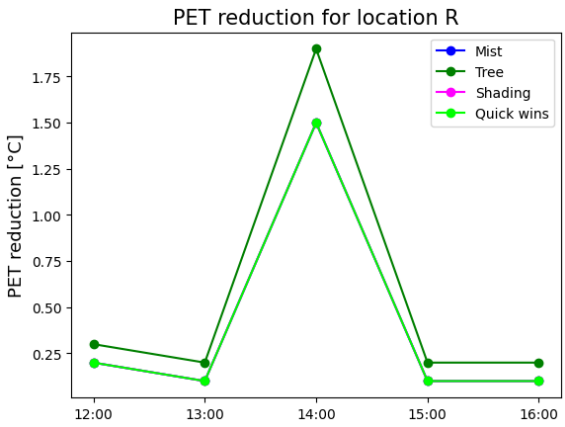
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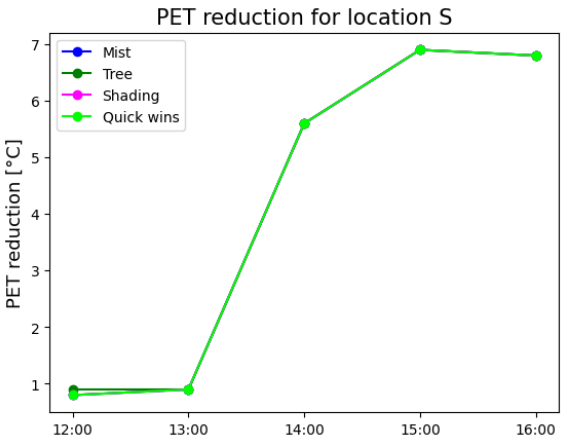
E.5P



E.5Q



E.5R



E.5S

Figure E.3: PET reduction for each location

E.4. PET Reduction Maps

In Figure E.4.0 to E.4.4, the results are plotted onto maps. Figure E.4 shows the PET values in the current situation. The other figures show the maximum PET decrease for each alternative intervention, i.e. the PET decrease at an optimal moment.



E.4.0: Maximum PET decrease for intervention 0, for each location



E.4.1: Maximum PET decrease for intervention 1, for each location



E.4.2: Maximum PET decrease for intervention 2, for each location



E.4.3: Maximum PET decrease for intervention 3, for each location

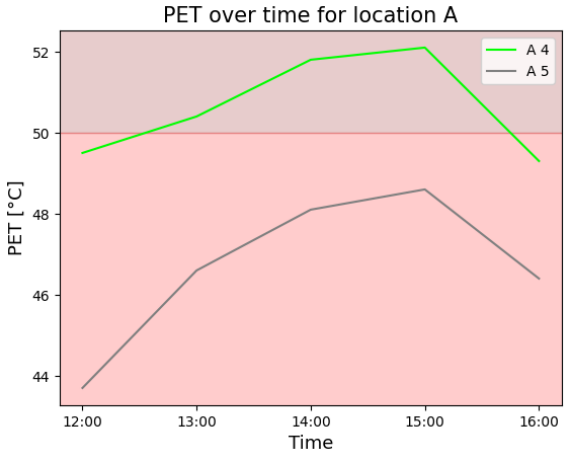


E.4.4: Maximum PET decrease for intervention 4, for each location

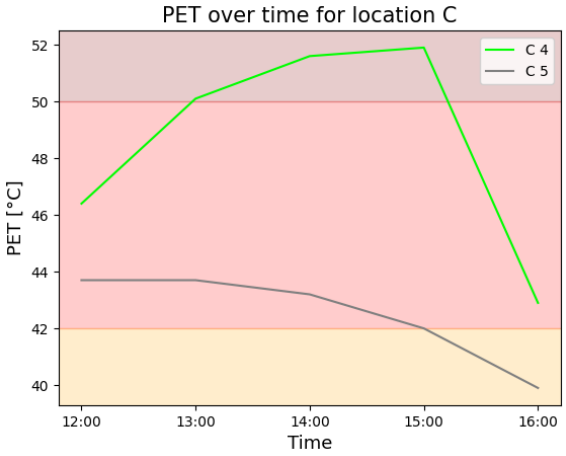
Figure E.4: Overview of PET maps

E.5. Average Circumstances

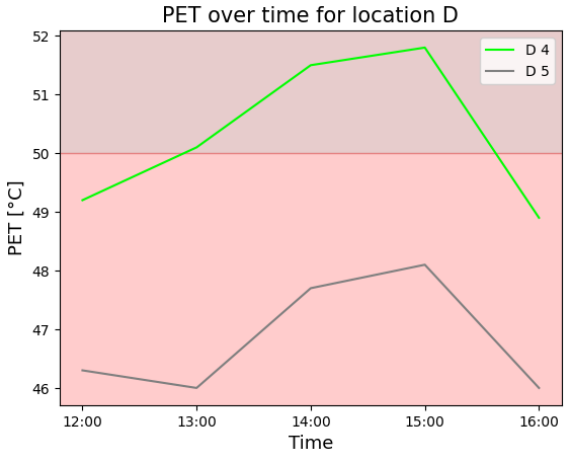
To analyse how the interventions affect a regular day as opposed to one with extreme temperatures, the PET calculations for the 'quick wins' were also conducted for an average day (grey) in September 2024, as opposed to an extreme event in the same month (lime). The thermal comfort classes are shown in dark-red (*very hot*), red (*hot*) and gold (*warm*).



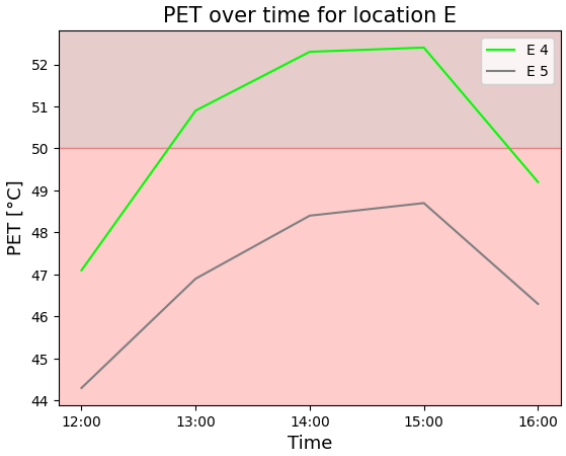
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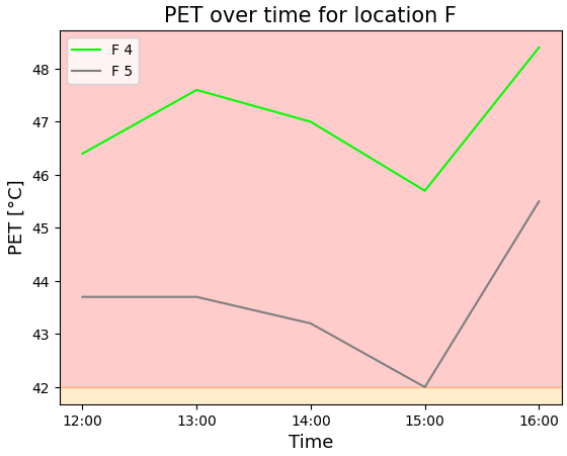
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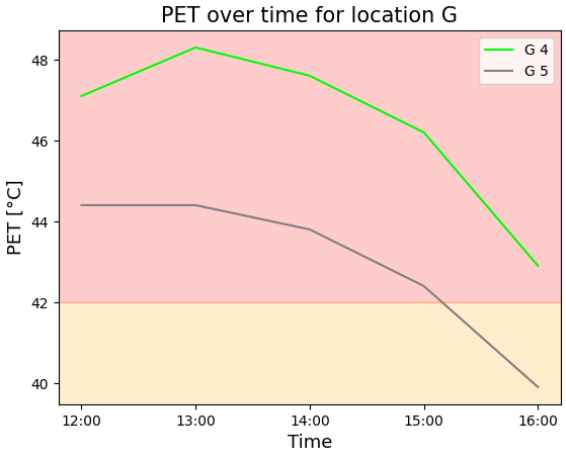
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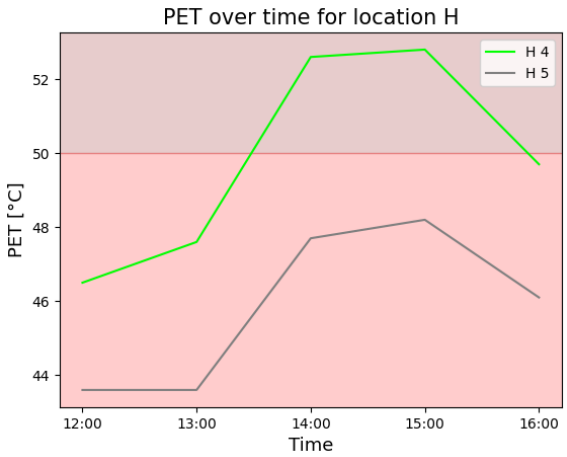
E.5E



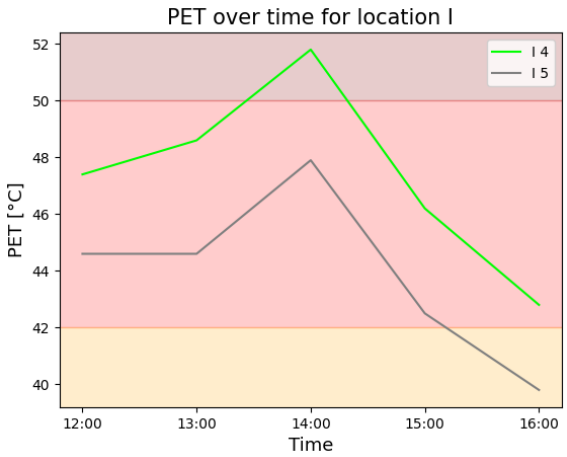
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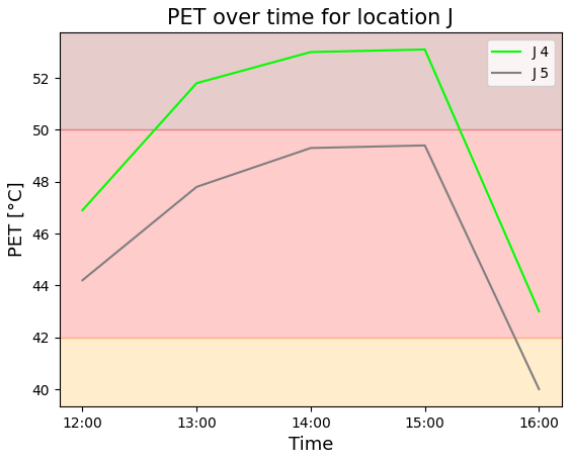
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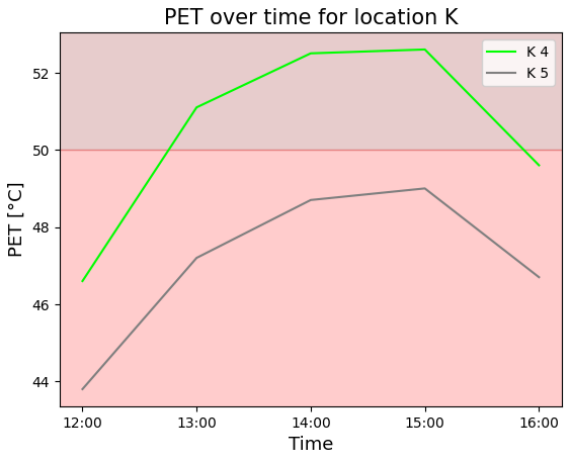
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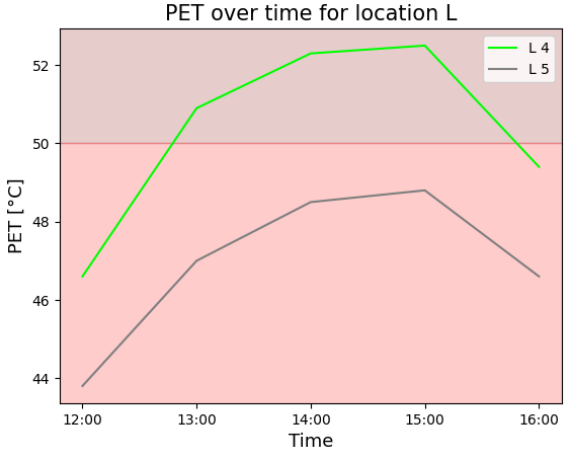
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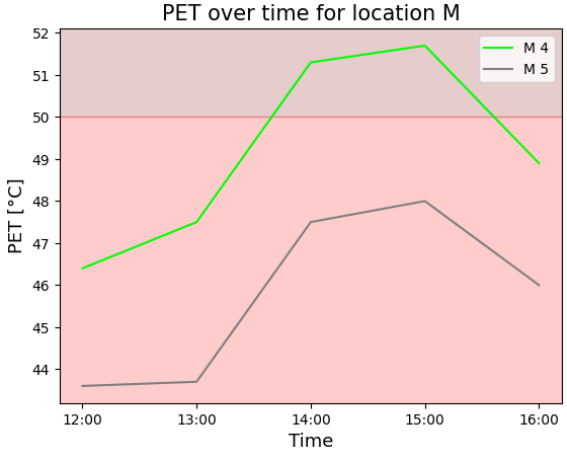
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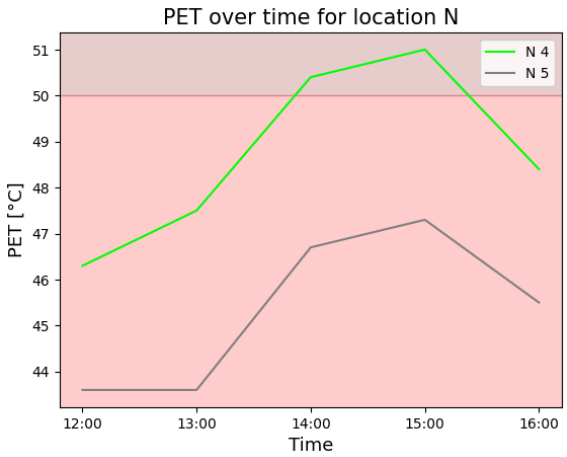
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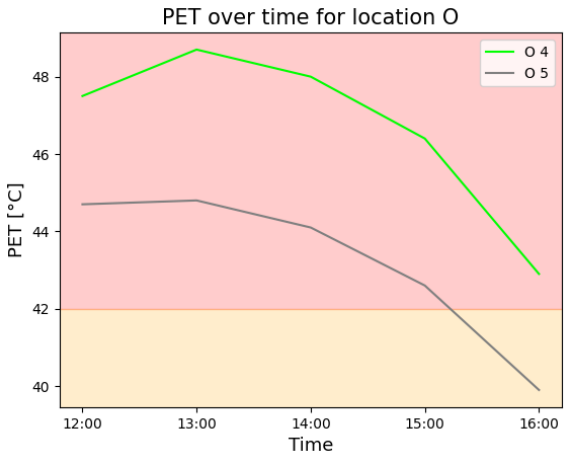
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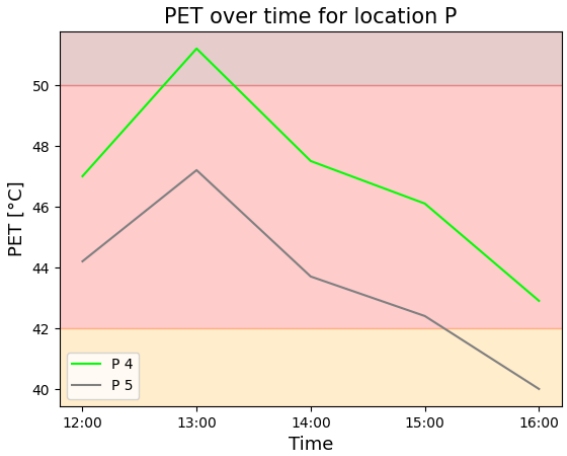
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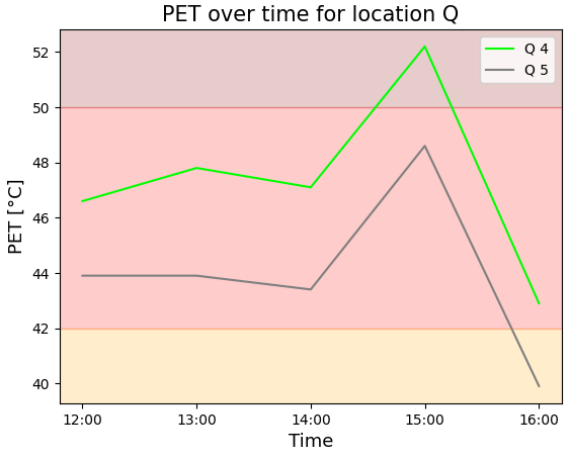
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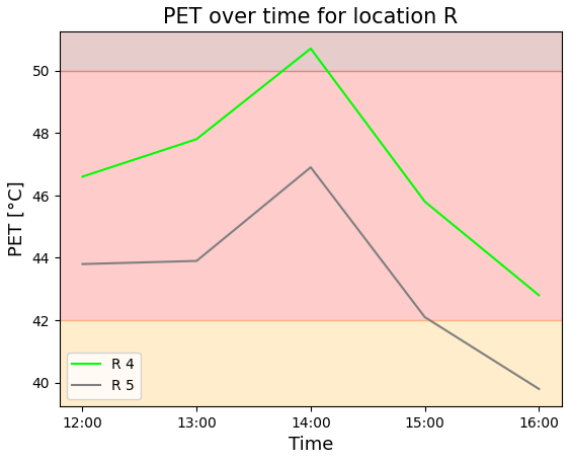
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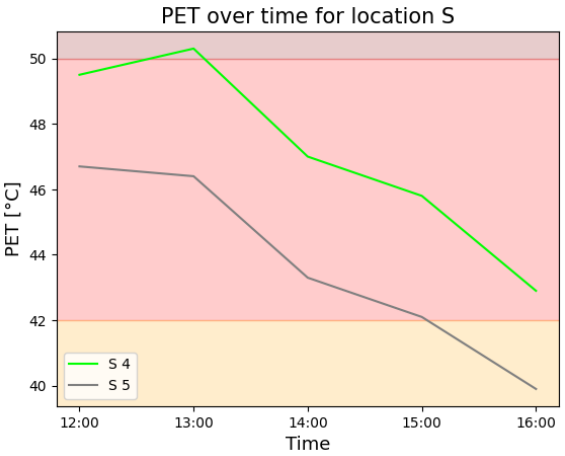
E.5P



E.5Q



E.5R



E.5S

Figure E.5: PETs for average situation (grey) and extreme case (lime)

E.6. Time Gain

Based on the results from the average circumstances in E.5, one additional calculation was run. For this last run, the input consisted of September average values for air temperature and vapour pressure over a longer time frame and for location K (middle of the left-hand paved part), as shown in Table E.3.

Table E.3: General input data for all locations on Wilhelminaplein

Date	Time	T_a (°C)	VP (hPa)
1.9.2024	10:00	32.3	33.1
1.9.2024	11:00	32.5	33.9
1.9.2024	12:00	32.5	33.7
1.9.2024	13:00	32.5	33.0
1.9.2024	14:00	32.6	32.0
1.9.2024	15:00	32.7	31.5
1.9.2024	16:00	32.4	31.3
1.9.2024	17:00	31.6	32.0
1.9.2024	18:00	30.6	32.8

The other variables (Lon, Lat, z, UTC+h, v, cc, α, β) or K have stayed the same. The results are displayed in Figure E.6.

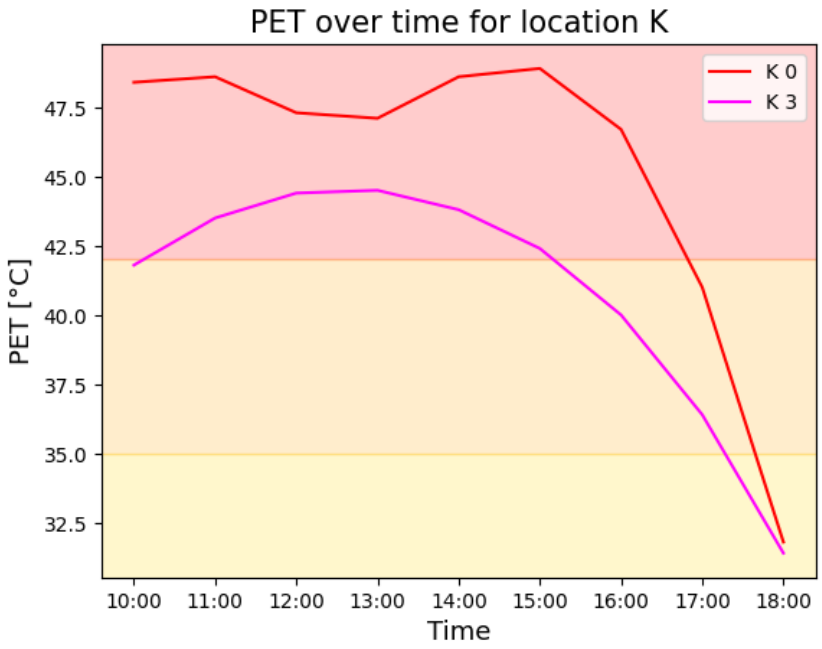


Figure E.6: PET over time for location K for current situation and intervention 3 on an average September day

E.7. Conclusions from PET Calculations

The PET in the current situation, under extreme circumstances, can get as high as > 50 °C in the middle of the square and the other unshaded areas. Even with adjusted thermal comfort ranges, these are considered *very hot*. Shaded spaces are 3-4 °C cooler than the open spaces but are still considered *hot*.

Most interferences only affect the PET locally. Shading has the biggest influence, which is evident from both artificial shading (E, J, K, L, M, Q) and natural shading (C, F, L, M, N, R, S). These reduce the PET by 4-7 °C. In the case of the misting system, an additional PET decrease is assumed based on the literature, for a total of over 10 °C decrease.

There are some cases where the interventions could potentially increase PET slightly. These increases can be explained by the complex interaction of objects with the environment. Not only can obstacles block sunlight, decreasing direct short-wave radiation, but they can also store or capture energy, increasing long-wave radiation. These increases, however, are generally very small.

As mentioned, the calculations from extreme meteorological circumstances return PET values that fall in the *very hot* category, *extreme heat stress*. This is not the standard. Choosing average air temperature and vapour pressure values for the month of September (still the hottest month of the year [26]) gives much more moderate PETs. In general, the PET in the average circumstances is 3-4 °C lower than in the extreme case. The PET sometimes drops into the *warm* category (*moderate heat stress*), reaching as low as 40 °C. This is, however, only in the locations with shading. The areas in the middle of the square, for example, still experience *strong heat stress*. This further emphasises the need for shading in those areas.

Even though the new PET values are still considered *warm* and indicating *moderate heat stress*, they do open up possibilities to stay on the square. Perhaps the heat stress at the hottest hours of the day is still too great to organise events, but around 3 or 4 p.m., the thermal stress could be deemed acceptable for certain low-key activities.

E.8. Stakeholder Design

Based on the presented results, a stakeholder workshop was given, which is described in Chapter 8.1. During this workshop, the most important stakeholders developed the additional design shown in Figure E.7. This design was later run in the model. The results are very similar to the aforementioned ones, as it was a combination of the proposed interventions. The most notable differences can be found in the central grass patch. Here, two extra trees are planted, and the grass area is increased, leading to even lower PET values. Removing the canopy, on the other hand, increases the PET locally (location O). Please note that the results in Figure E.7 are mean values, so big PET differences in one moment of time have only a small effect on this value.

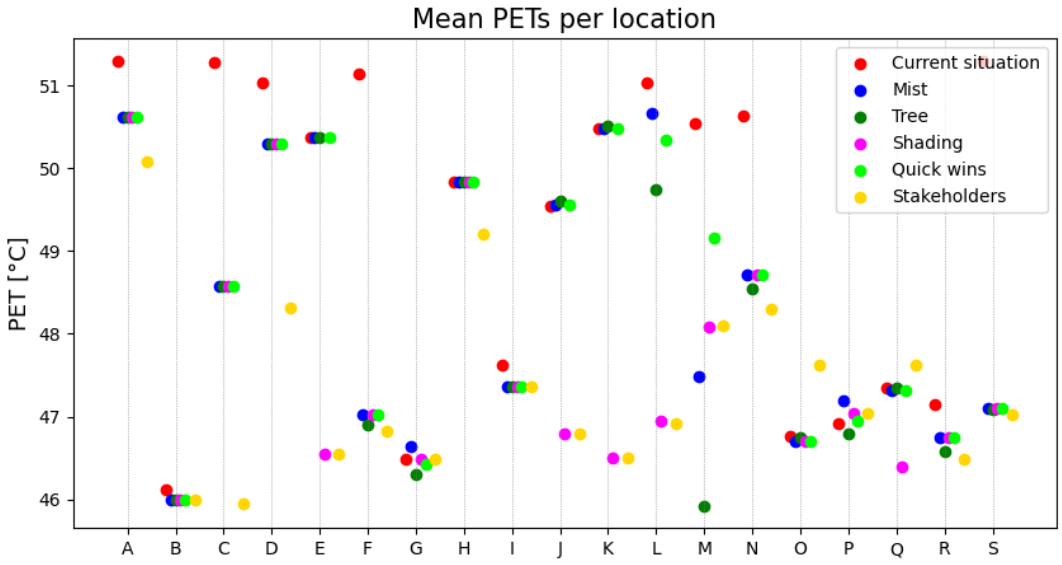


Figure E.7: Mean PET for each location and design, including the stakeholder design



Figure E.8: Map of PET reduction in Stakeholder Design

Appendix F

Reference projects

To determine the effectiveness of our proposed strategy, several other reference projects for climate resilience are analysed in this part of the Appendix.

F.1. The Garden City of Singapore

It has been studied in detail how introduction of greenery is a vital step in combating the urban heat island effect: vegetation decreases the ground temperature by providing shade and decrease the air temperature through the process of evapotranspiration [160]. The presence of tree and plant roots also serves a crucial role in storing water in the soil. No better example of a city investing in greenery can be found than the city of Singapore. In 1967 the ”garden city” initiative has been introduced, with the goal of turning Singapore into ”a city with abundant lush greenery and a clean environment in order to make life more pleasant for the people” [161]. Singapore has actively pursued this vision, dedicating approximately 47 % of its surface area to greenery by 2020 [162]. The efforts have borne fruit, with a 4.01 °C difference being reported between ‘urban’ and ‘rural’ areas in the city [163]. Although Singapore’s climate, particularly its precipitation patterns, differs from Curaçao’s, the introduction of greenery to mitigate urban heat stress remains effective. Studies have well documented its positive impact, even in arid regions [160].



Figure F.1: The garden city of Singapore [164].

F.2. Green Roofs

An up-and-coming technology for climate adaptation are blue-green roofs. Most research on the effectiveness of blue-green roofs have been in Mediterranean climates, with the research on their effectiveness in an arid climate being somewhat limited. An economic behaviour study on blue-green roofs for social housing was performed in 2020 in Mexico by Hernández et al. [165]. Mexico has a climate somewhat comparable to Curaçao in terms of temperature and aridity [166]. The study found a 4.7 °C decrease in indoor temperatures for buildings that had a green roof installed compared to buildings with a regular roof in locations with warm weather. With a significantly cooler indoor temperature, the use of air-conditioning dropped by 10.3 %. In the case of Willemstad, where many air-conditioning units are placed at street level, this decrease has the potential to also mitigate excess heat caused by said air-conditioning outside. A payback period of 8.8 years was estimated for the implementation of the blue-green roofs.

Besides cooling, blue-green roofs are also a valuable tool for storm water management in urban areas: a review by the ICCREM (Innovative Construction Project Management and Construction Industrialization) in 2019 found a retention of 10–60 % and 30–68 % for green roofs and green-blue roofs respectively during small rain events [167]. This retention means that less water leaves the roof during the precipitation event, alleviating the soil, streets and sewer system. An important note however is that most precipitation-based flooding in Curaçao are due to extremely heavy rainfall events, meaning that investing in climate adaptive roofs for the sake of water management in Curaçao are likely not the most effective measure.



Figure F.2: A green roof in Mexico-City [168]

F.3. Freiburg Bächle

”Nestled in the southern corner of Germany near the Swiss and French borders, the city of Freiburg has long been considered a model of sustainable development for Europe and the world” [169]. In the context of sustainability, Freiburg is recognized for its excellence in energy planning, water conservation, and achieving high transportation modal splits. An iconic example of how Freiburg excels in water management are the bächles. A bächle is a small channel through which shallow streams of water flow through the city. Constructed in the 12th century, these bächles were originally built to supply the people with clean water to drink, use for cleaning, or to put out fires [170]. In later years, while these primary functions have been phased out, the bächles are still maintained due to their positive influence on the city character. This is not the only modern purpose however, as the water flowing through open channels is known to have a significant cooling effect through evaporative cooling and convective heat transfer. While the effects of the bächles in Freiburg have not been researched, open water sources in urban areas have been found to have a significant cooling effect on the surrounding area [73].



a) A Bächle in Freiburg [171]



b) A Bächle in Freiburg [172]

Figure F.3

F.4. Beenleigh Town Square

The Beenleigh Town Square, located in a Logan suburb near Brisbane, Australia, was once a six-way roundabout [173]. Starting in 2014, it was transformed to provide a community space [174]. The square is divided into six parts, each with its own functions. One of its most prominent features are the decorative shading circles. These provide two large shaded areas within the square, along with natural shading from trees. They form an artistic way to create comfortable zones, see Figure F.4.



Figure F.4: Decorative circled shading creating a vibrant area [175]

Thanks to the innovative design that won several architectural awards, it is useful for social, cultural and economic activities. The cultural aspect was enhanced by collaborating with indigenous artists. Pedestrians were given priority in the design, with safer traffic control and street furniture. The area itself was made safer with lighting. Lastly, the redesign emphasised existing urban features [175].

F.5. Other Inspiration

In this last section some figures are shown which are an inspiration for the interventions. The combination of creating shadow and an attractive coloured structure can be seen in Figure F.5. For a large shadow structures creating shade over a pavilion in Bahrain, see Figure F.6.



Figure F.5: Town Square in San Antonio, Texas [176]



Figure F.6: Pavillion of Bar al Bahrain [177]

Appendix G

Interviews

This appendix provides an overview of the interviews and survey conducted for this work. Below a table with all interviews conducted for this study is shown. For more details on any particular interview, please contact the authors of this report.

Table G.1: Overview of all interviews conducted for this study

Interviewee	Function	Organization
20 Students (Survey)	Students	University of Curaçao
Caroline Gonzalez Manuel	Sector Director	VVRP
Michelle Metsch	Chairwoman	DMO
Pédzi Girigori	Chief Operations Officer	METEO
Café owner	Owner	Plein Café Wilhelmina and De Buren Curaçao
Zarja Garmers	Director	ZARJA Architectures
Christopher Vierbergen	Landscape Architect	ZARJA Architectures
Rene Gabriela	Urban Planner	ROP
Gwido Jansen	Senior Policy Advisor	MEO
Miriam Jonker	Policy Director	VVRP
Donovan Angelina	Head of Heritage	ROP
Melvin Cijntje	Traffic Engineer	OW
Corina Regales	Real Estate Portfolio Manager	APC
Clifford de Lannoy	Inspector Environment and Nature	GMN

G.1. Survey students UoC

A survey was conducted to see how students see Punda and what improvements they think should be made. No personal data is collected. The survey is approved by the professor of these students. The questions in the survey are written beforehand and consist of multiple-choice and open questions. The survey was tested before the participants filled it out. Participation was not mandatory: the professor mentioned the survey to the students during a lecture.

Respondents

In total, the survey was filled out by 20 people, all of which are currently studying at the social works facility of the University of Curaçao (UoC). It was not specifically asked in the survey, but it can be assumed that their age range lies between 17 and 35 years old. Of the 20 respondents, 16 were born in Curaçao, 2 were born in the Netherlands, and 2 were born elsewhere (question 1).

Results

The first questions relate to how they are currently using Punda. They were asked how frequently they visit Punda and what their reason for visiting is. 35 % of the respondents visit Punda at least once per week, but the majority of 65 % do not visit Punda weekly. Their main reasons for visiting are shopping, strolling, eating, or meeting with friends. The Venezuelan fruit market was mentioned a few times explicitly.

Next, the participants were asked what places they like to visit in Punda. Different eating facilities, landmarks, and squares were mentioned, but the most noted areas were Wilhelminaplein, which had five mentions, and the Venezuelan fruit market, which had four mentions.

The next questions were about the positive aspects of Punda and the aspects of Punda they would like to see improved. Common positive responses were the food, the atmosphere, the history, the murals, the beautiful buildings, and the events. Possible improvements to Punda that were mentioned were that there should be more activities, it should be cleaned better, there are many shops that have closed down, and the buildings should be renovated better.

For the penultimate question, respondents were shown a map of Punda, and they could pinpoint where they would like to see an improvement. This generated the map shown in Figure G.1.

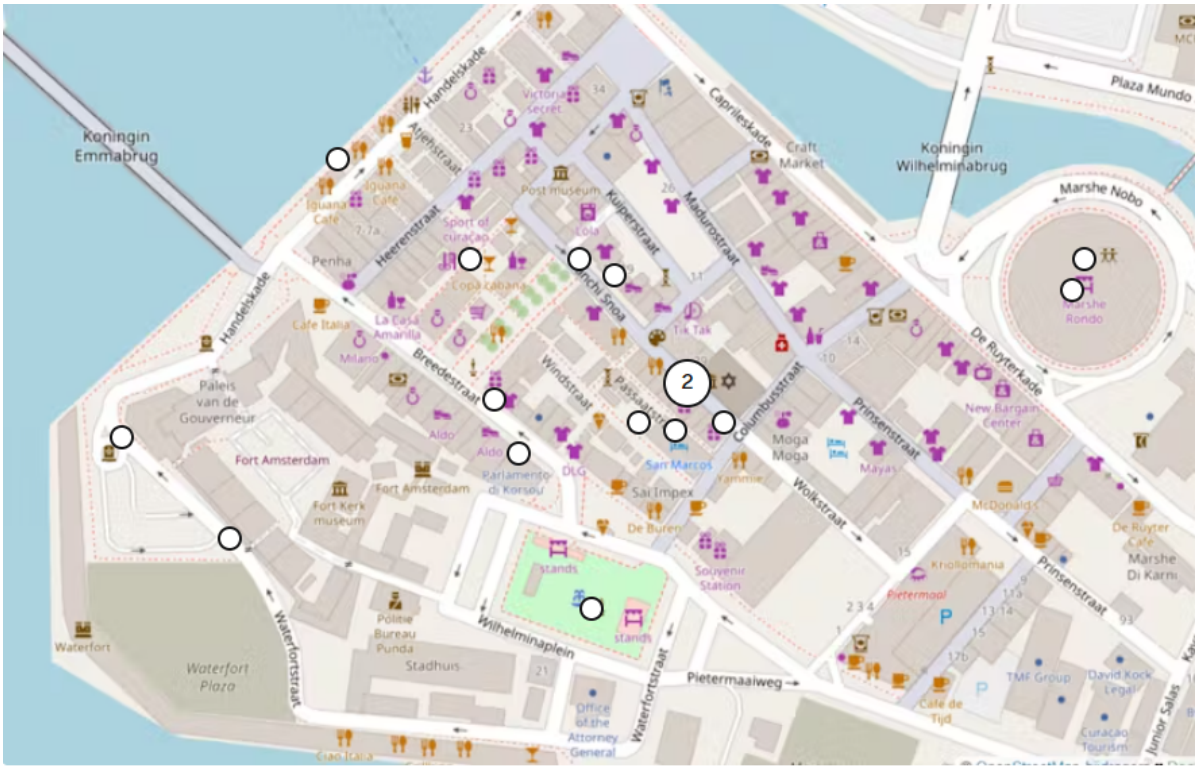


Figure G.1: Possible improvement areas following the survey, marked with white circles [53]

The last question was a multiple-choice question about whether they would visit Punda more often if it had more cool spots. No one responded that they would not visit more often, and one of the respondents would not visit more often but would stay longer. The majority, with twelve responses, would visit Punda more often, and four respondents would visit more often and stay longer.



Figure G.2: Question 3 of the survey



Figure G.3: Question 4 of the survey



Figure G.4: Question 5 of the survey



Figure G.5: Question 6 of the survey

Conclusion

The aim of the survey was to inquire how the local inhabitants view and use Punda. The first questions regarding their reasons for visiting and the locations they like to visit do not provide surprising findings. These activities are regarded as Punda's main functions, so these responses were in line with expectations. The questions regarding the positive aspects of Punda highlighted the aspects of Punda that the respondents value the most. Overall, it became clear that the students valued the history and character of Punda and that this should definitely remain. The respondents do see many possible improvements in the level of hygiene and overall maintenance of the area. The survey also highlighted that there are several spots in Punda that could use an improvement. Lastly, the respondents indicated that they would visit Punda more often and longer if it had more cool spots.

Limitations and considerations

The results of the survey are by no means scientifically accurate or used to draw statistically significant conclusions. The goal was to gain insight into how the local communities view the area. It should also

be noted that this community is not represented fully, as only a small group of students participated in the survey. When writing the questions, the aim was to write them in the least biased and steering way whilst keeping them relevant to the study. For most questions, this was done successfully, but with the last question (would you visit Punda more often if it had more cool spots?), the question was framed slightly towards a positive answer. Lastly, the question where the participants could pinpoint an area that they would like to see improved could have been more effective if participants also got the opportunity to explain their choice with the improvement they would like to see. With the current results, very few conclusions can be drawn from the results.

Appendix H

Stakeholder Workshop

A crucial component for the implementation of the designs proposed in this work is to have the responsible parties, OW, GMN, ROP, and the sector director of VVRP, agree on one idea. For this purpose, a stakeholder workshop was given on October 25th. Attendees included representatives from VVRP, OW, GMN, and MEO, the author of *World of Punda* and a landscaping architect from Zarja Architecture. Students and teachers from TU Delft, Uoc and The Hague University of Applied Sciences (Haagse Hogeschool) were also present.

During the workshop, the designs shown in Appendix K were presented, along with the corresponding effects on the PET. Afterwards, the stakeholders were placed in groups of 4-7 and were asked to discuss their preferred set of interventions.

The preferences between the different groups were varied, with some opting for ideas with a higher chance of succeeding and others preferring more ambitious plans. All groups agreed that the 'quick wins', rerouting of the road north of Wilhelminaplein, and some type of cool spot should be implemented.



Figure H.1: Final design group 1

H.1. Group 1

Group 1 consisted of representatives from VVRP, DMO, Zarja Architecture. Their main objective was to keep things simple. They would opt for the big tree as the centrepiece of the square. If possible, they would try to incorporate a misting system along with a centrepiece tree. They would also include the shading canvas if enough money is available. For this design, holding a contest was proposed so that the people of Curaçao would be involved in the designs. Adding shades to Hendrikplein parking on the east of Wilhelminaplein was also part of their ideas.

Group 1 would embrace the quick wins and the car-free pedestrian area. That way, the terraces can expand. Lastly, they would prefer green additions to the parking lots on the west.



Figure H.2: Final design group 2

H.2. Group 2

Group 2 had the most important stakeholders from VVRP, MEO, GMN and OW. Another important stakeholder, ROP, was not present during the workshop. They were very ambitious in their chosen interventions. Group 2 valued the event function of the square very much. For this purpose, they would include the shading canvas and see how they can clear any obstructions from the square. They would remove the concrete canopy entirely to create a line of sight from Hendrikplein. The Wilhelmina statue would have to be relocated. For this, they opted for the car-free pedestrian area.

As the centrepiece of the square, they would reintroduce a fountain. Although they would prefer trees in the parking areas, they would want to investigate the use of solar panels, as they could provide energy for said fountain. They would also remove/relocate the ice cream bar and place an artwork in its place.

Since this group contained the most important stakeholders, their chosen set of interventions is further worked out, as can be seen in Figure K.4.

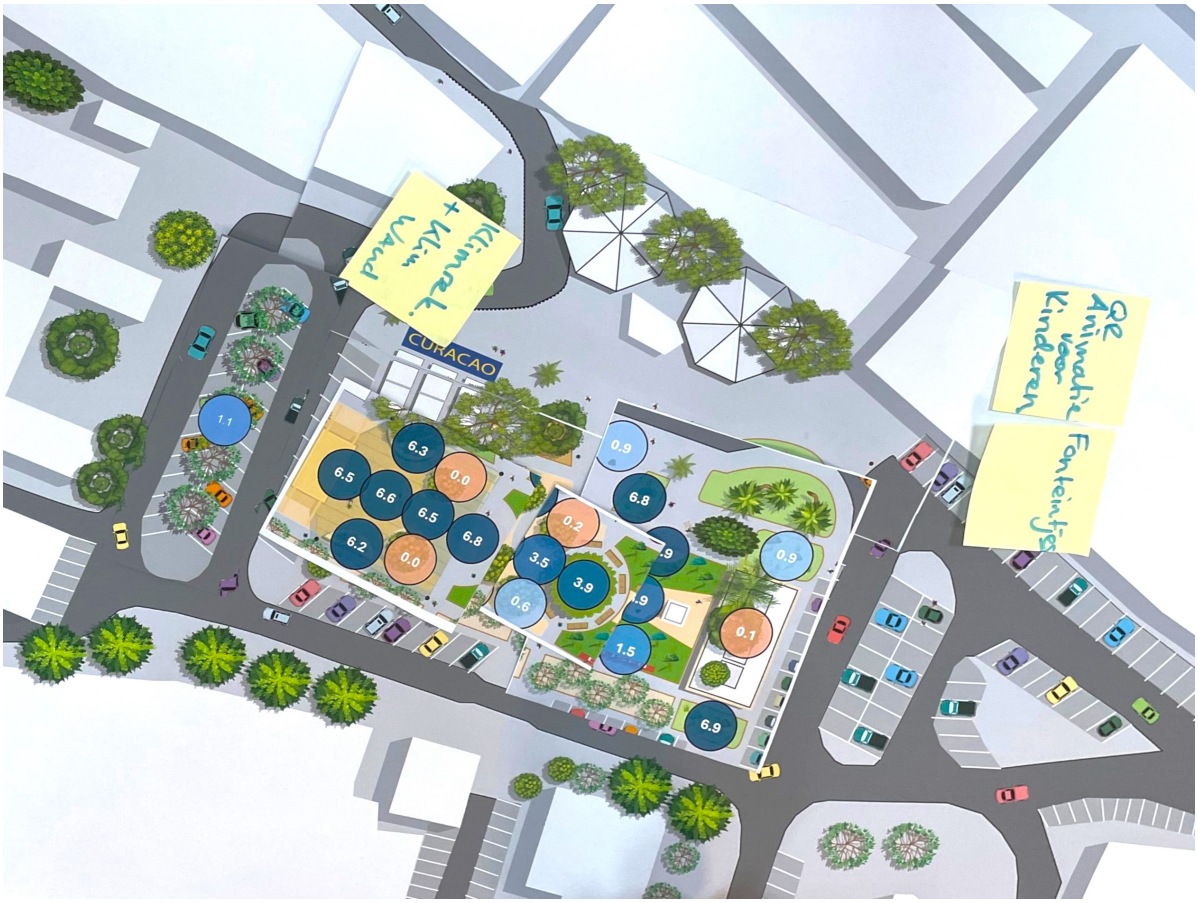


Figure H.3: Final design group 3

H.3. Group 3

Group 3 consisted of students and representatives from the TU Delft and UoC. Their design was very similar to that of group 1, with the quick wins, shading canvas and big tree. However, they also proposed a dry fountain as a centrepiece for children to play with.

They would also try to improve features around the square. They would remove/replace the ice cream bar and devised an idea for a bouldering wall (although not thoroughly elaborated) and QR codes for more information on Punda.



Figure H.4: Final design group 4

H.4. Group 4

The last group also consisted of students and representatives from the TU Delft, The Hague University of Applied Sciences and UoC. They chose to include the quick wins, a shading canvas and a fountain. The misting system could be incorporated into the concrete canopy. They would also want to have more options for food and drinks, like food trucks and a water tap.

Appendix I

Law

I.1. EOP

Below are the abbreviated articles of the EOP Chapter 4. This is the chapter concerning the Inner-City, so this is the chapter relevant to this project.

- 1.a: The city centre must be attractive with preservation and restoration of the historic character.
- 1.b.3: The living environment needs to be improved and the recreational functions must be developed.
- 2.a.5/6: Buildings and facilities that improve recreational purposes are permitted.
- 2.c: Constructions or buildings cannot disturb the cityscape.
- 2.d: Functions that may pose a hindrance are banned.
- 3.a: Any demolition of a building requires a permit.
- 3.b: Demolishing existing structures will not be allowed if the harm to the cityscape is greater than the improvements.
- 4.a.1: The existing or historical pattern of streets, public spaces and building spaces need to be maintained.

Note that these articles are translated from Dutch and have been abbreviated. Also note that there are many more goals described in the EOP report that are not mentioned here because they do not apply directly to Wilhelminaplein, or because they overlap with the articles above.

I.2. Bouw- en Woningverordening 1935

Below are the articles of the 'Bouw- en Woningverordening 1935' law. This law encompasses all regulations around the construction of residential buildings. The following list contains all the regulations that are relevant to this project.

- A building is defined as any of the following:
  - Each stand-alone room or space
  - Each complete set of rooms or spaces
  - Any completely or partially enclosed wooden structure intended for residential use
  - Any non-residential wooden structure with a volume of more than twenty cubic metres
  - Any storage or warehouse for liquids with a volume of more than two cubic metres
  - Any installation for the intake and removal of liquid and solid waste, insofar as it is connected to the ground, anchored to the ground, or rests on the ground;
  - Buildings including grandstands, observation towers, lift towers, constructed masts, windmills, chimneys, tall fences and walls, and similar structures that, if poorly constructed, could pose a danger to users or the surrounding area; tents are not considered buildings;
- Article 7: It is prohibited to erect a building, renovate part of a building, or allow a building to be erected or renovated:
  - a. without compliance with the provisions set forth by or under this regulation;

  - b. without a building permit, unless Article 10 or § 5 of this regulation applies;
  - c. in deviation from the provisions of the building permit, unless additional approval is granted.

- Article 16:

  - 16.1.8: The application for a building permit mentions the name, first name, occupation, and residence of the applicant and is accompanied by a drawing in duplicate, made to a scale of 1:100, indicating the placement of the building in relation to the road and the adjacent plots.
  - 16.2: For simple buildings without a floor, with a ground area of no more than one hundred m^2, the submission of a drawing is not required, provided that the data mentioned under 1° to 8° are sufficiently clearly described.

- Article 22: A decision to grant a conditional building permit or to refuse it in whole or in part must always be substantiated and can only be based on one or more of the following circumstances:

  - 1°. that the application, the drawing, the description, or the building or part of the building does not comply with the regulations given by or under this ordinance;
  - 2°. that the building, also in relation to the applied construction method, cannot be considered to have sufficient strength to ensure that it poses no danger to the lives of the inhabitants or users or the surrounding environment;
  - 4°. that the use of the building or part of the building is considered harmful to public health or the health of the users;
  - 5°. that the building or part of the building, due to its location or construction method, will disfigure or cause nuisance or be a fire hazard to the surrounding area;
  - 6°. that the road on which the house will be located does not meet the requirements concerning its alignment, width, and construction, taking into account the nature of the house and the requirement for accessibility of the road for government services.

- Article 42.1: It is prohibited, without a permit from the administrative board, and otherwise than in accordance with the conditions attached to the permit or the prescribed height, dimensions, or distance from the ground floor, to place, have placed, or have a sidewalk or step, either connected to a building or not, on a public road.

It should be noted that these articles have been translated from Dutch and have been summarised to only include information relevant to this work. For the original articles, see the original document: [130].

Appendix J

Design Proposals

These are the three preliminary designs. Note that the final designs can be seen in Appendix K. These are still included to give context on the design process as well as the feedback given by experts and stakeholders.



Figure J.1: Poster design proposal 1

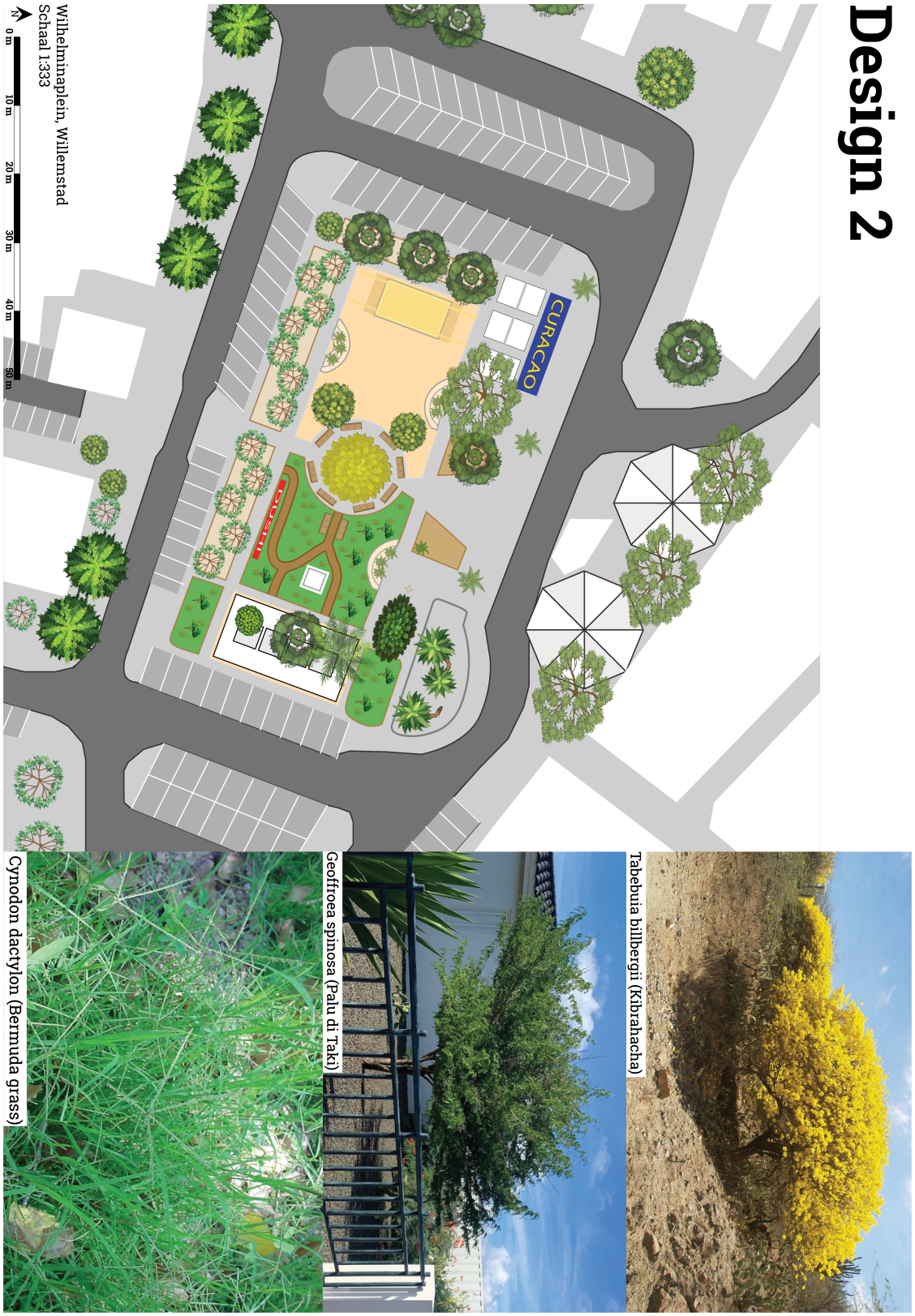


Figure J.2: Poster design proposal 2

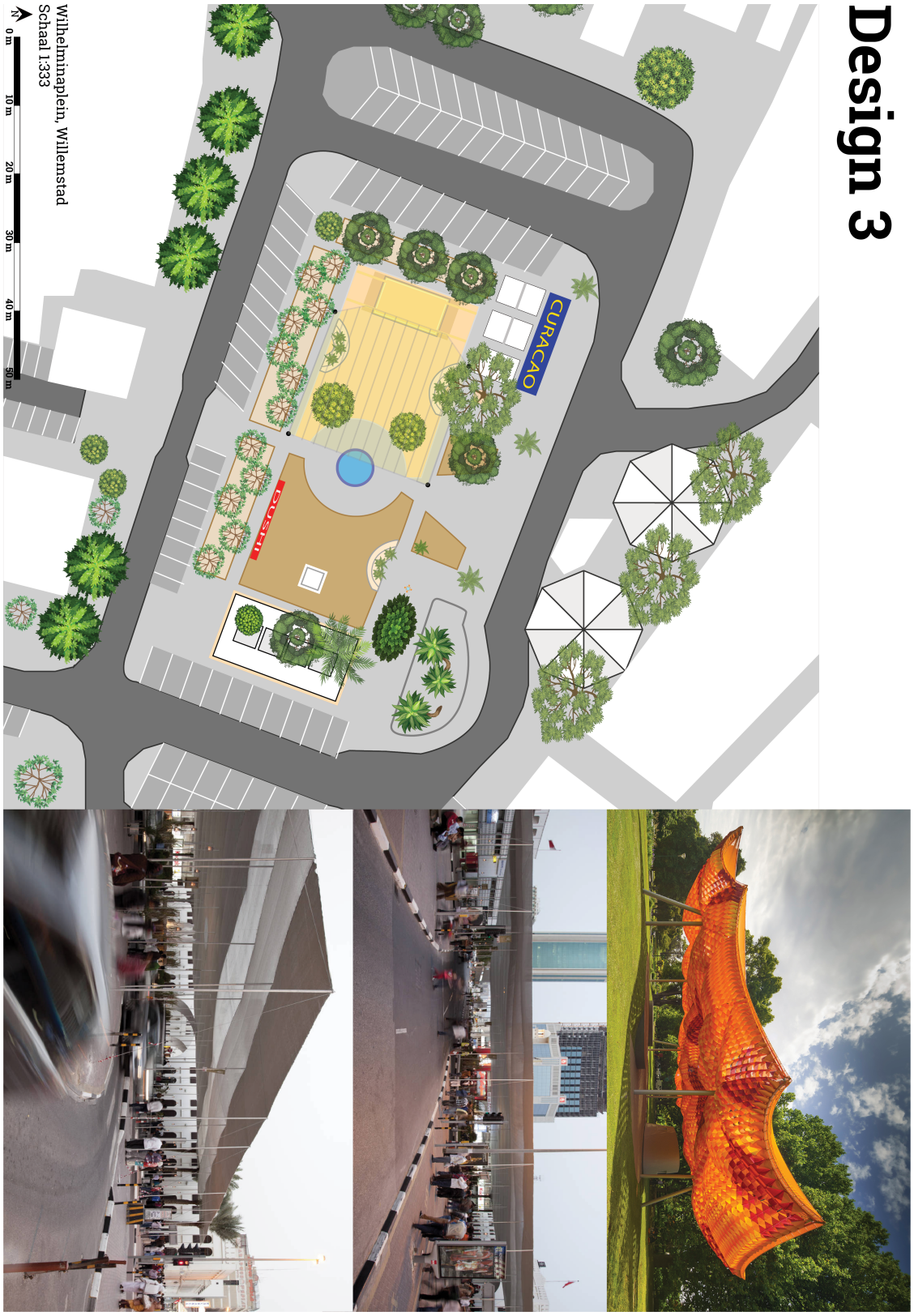


Figure J.3: Poster design proposal 3

Appendix K

Final Designs

These are the final designs that were presented during the stakeholder workshop covered in Section 8.1 and Appendix H.



Figure K.1: Final design 1



Figure K.2: Final design 2



Figure K.3: Final design 3



Figure K.4: Final design 4

Appendix L

Photos Wilhelminaplein

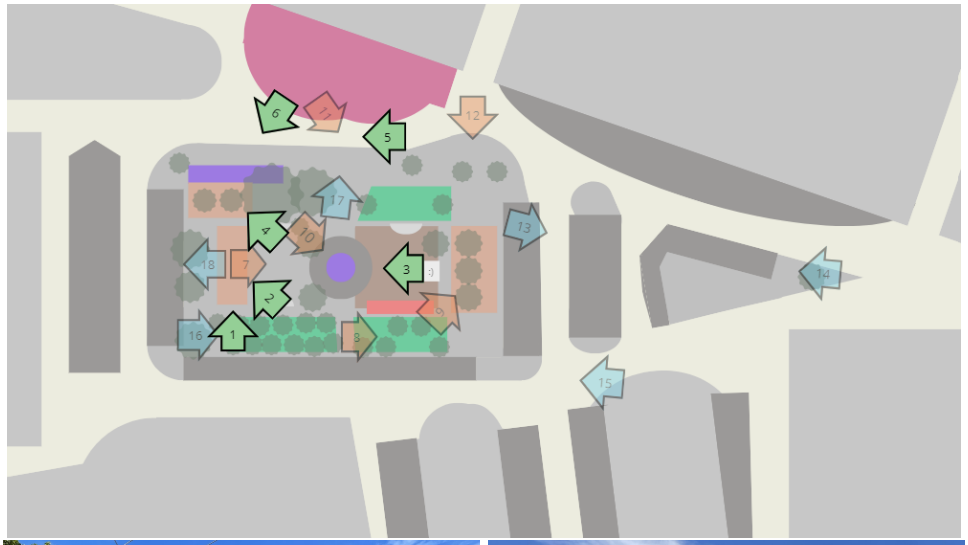
To provide an overview of Wilhelminaplein, a series of images is presented, including both contemporary and historical photographs. The first page features two historical images, while the subsequent pages display the current state of the area, with a map indicating the location and direction of the photographs. The collection comprises 18 images in total.



Figure L.1: A Postcard made of Wilhelminaplein in 1903 [178]

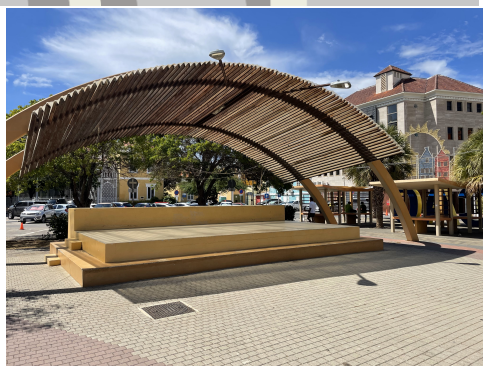


Figure L.2: A Postcard made of Wilhelminaplein in 1970 [61]





1: A side view of the podium



2: A front view of the podium



3: A central view of the square facing the podium



4: A bench, with the unused vending stalls behind it

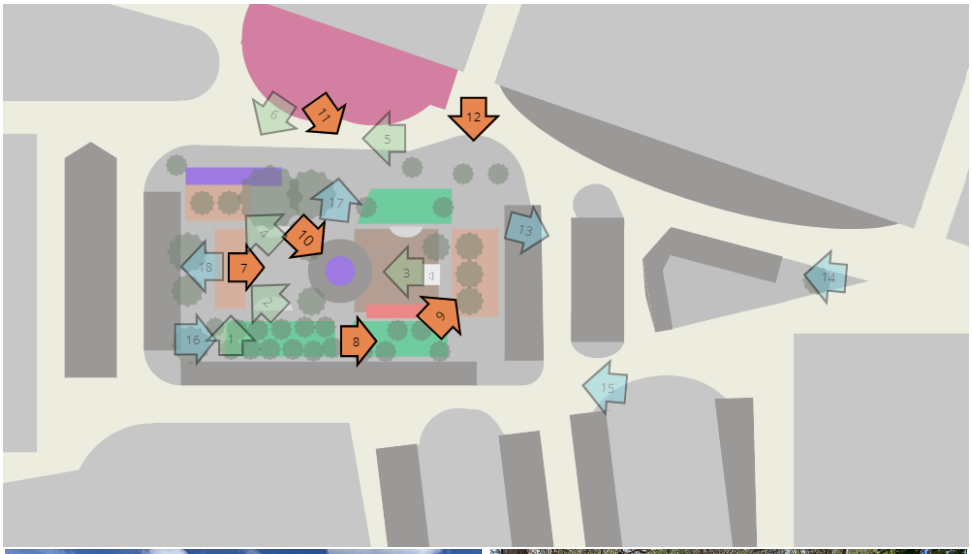


5: The street, towards the CURACAO sign



6: The CURACAO sign

Figure L.3: Map of Wilhelminaplein with corresponding photos 1-6 made on 27-09-2024. Arrows mark direction and location of photo





7: A central view of the square, facing the Wilhelmina statue



8: The play area, featuring a giant iguana sculpture



9: The Canopy at the east-end of the square. Note the lack of benches



10: The remnants of the fountain in the center of the square Also note the DUSHI sign

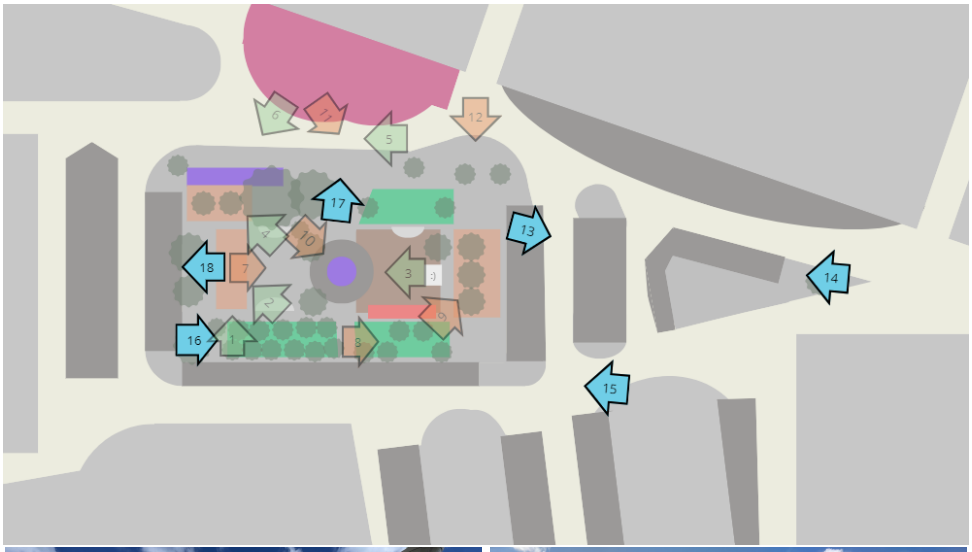


11: A central view of the square from the north-side, featuring the ChiChi sculpture



A north-side view of the square, with the canopy clearly visible

Figure L.4: Map of Wilhelminaplein with corresponding photos 7-12 made at 27-09-2024. Arrows mark direction and location of photo





13: The eastern parking lot towards Pietermaai



14: Hendriksplein and the surrounding parking lot



15: A small parking lot at the south-east side of the square



16: A small bench in the shade of some trees at the southern side of the square



17: The backside of the ChiChi sculpture



18: The westside parking garage

Figure L.5: Map of Wilhelminaplein with corresponding photos 13-18 made at 27-09-2024. Arrows mark direction and location of photo

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