NATURE-BASED DESIGN FOR WATER-SENSITIVE CITIES: A STREET-SCALE COMPUTATIONAL APPROACH

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ABSTRACT

NATURE-BASED DESIGN FOR WATER-SENSITIVE CITIES: A STREET-SCALE COMPUTATIONAL APPROACH

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Cities grow and develop at an unprecedented pace, but that does not necessarily bring similar attention to water management in cities. Water unconscious development of the cities leads to water scarcity and disturbance of the natural cycle of water and eventually creates unhealthy places for all the living inside the city. Nature-based solutions help us tackle water-related problems and harvest rainwater in our cities while simultaneously improving the well-being of the habitants in various ways. Numerous nature-based solutions are developed and applied around the world. However, their integration into the city at the street-scale differs based on the context. Countries set their best methods to optimise the efficiency of rainwater harvesting and changes in their urban planning.

This thesis aims to develop an early design approach that can be used to integrate nature-based water management treatments at the street-scale. It further intends to assess the effect of different context interpretations, different water management scenarios and their impact on the system's efficiency. The research is conducted via a study area in Ankara, Tunus Street. With the case study, the suggested design approach is followed, and a proposal for the area is designed to compare with the existing environmental performances.

Keywords: water management, design approach, nature-based solutions, street-scale.

ÖZ

SUYA DUYARLI ŞEHİRLER İÇİN DOĞA TEMELLİ TASARIM: SOKAK ÖLÇEĞİNDE HESAPLAMALI BIR YAKLAŞIM

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Şehirler benzeri görülmemiş bir hızla büyümektedir ve gelişmektedir, ancak bu, şehirlerdeki su yönetimine benzer bir ilgi göstermemektedir. Şehirlerin su konusunda bilinçsizce gelişmesi, su kıtlığına ve suyun doğal döngüsünün bozulmasına yol açmakta ve nihayetinde şehir içindeki tüm canlılar için sağlıksız alanlar yaratmaktadır. Doğa temelli çözümler, su ile ilgili sorunların üstesinden gelinmesine ve şehirlerimizdeki yağmur suyunu hasat etmemize yardımcı olurken aynı zamanda sakinlerin refahını çeşitli şekillerde iyileştirmemize yardımcı olmaktadır. Dünya çapında çok sayıda doğa temelli çözüm geliştirilmekte ve uygulanmaktadır. Ancak, sokak ölçeğinde kente entegrasyonları bağlama göre farklılıklar göstermektedir. Ülkeler, yağmur suyu hasadının verimliliğini ve şehir planlamalarındaki değişiklikleri optimize etmek için en iyi yöntemlerini geliştirmektedir.

Bu tez, doğa temelli su yönetim araçlarını şehir bağlamına cadde ölçeğinde entegre etmek için kullanılabilecek bir ön tasarım yaklaşımı geliştirmeyi amaçlamaktadır. Ayrıca, farklı bağlam yorumlarının etkisini, farklı su yönetim senaryolarını ve bunların sistemin verimliliği üzerindeki etkisini değerlendirmeyi amaçlamaktadır. Araştırma, Ankara, Tunus Caddesi'ndeki bir örnek alan üzerinden yürütülmüştür.

Vaka çalışması ile, önerilen tasarım yaklaşımı izlenmiş ve mevcut çevresel performanslarla karşılaştırılmak üzere alan için bir tasarım önerisi geliştirilmiştir.

Anahtar Kelimeler: su yönetimi, tasarım yaklaşımı, doğa temelli çözümler, cadde ölçeği.

Whoever makes this journey possible and enjoyable.

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NBS	Nature-Based Solutions
RWH	Rainwater Harvesting
LID	Low Impact Development
SUDS	Sustainable Urban Drainage Systems
WH	Water Management

CHAPTER 1

INTRODUCTION

This thesis focuses on developing an early design approach for designers to integrate nature-based treatments in a water-sensitive approach to cities at street-scale.

1.1 Problem Definition

Water management has been a subject that civilisations focus on for thousands of years. Water management integration has become more complicated and challenging with the cities' paced development. With the addition of profit and human-centred city developments, water svehicularcities and water disturbance have become a significant problem area for cities. Moreover, climate change puts additional stress on the water supply systems leading to the recreation of underground water reaching and coming out of the city. Therefore, authorities and governments develop precautions to manage water in various scenarios.

Different water management systems are used worldwide, depending on the city’s needs. Indians built stepwells to collect rainwater (Figure 1. Indian Stepwells), Rom. Romans built aqueducts to bring water from long distances (Figure 2. Roman Aqueducts). The Corriental reservoir filtration system was constructed to sanitise their water 2000 years ago (Figure 3. Corriental Reservoir Filtration System).

Figure 1. Indian Stepwells

Figure 2. Roman Aqueducts

Figure 3. Corriental Reservoir Filtration System

Contrary to past examples, today's methods to tackle water management in cities are much more efficient and cheaper. Also, the focus has shifted from the evacuation of water and providing water to cities from great distances to sanitisation, improving the urban landscape and reducing infrastructure costs (.AI Lawrence et al., 1999). Grey infrastructures which focus on immediate evacuation of water via sewages have been turning into green infrastructures which treat water as a source rather than a waste. The shifting paradigm brought many approaches alongside, such as Best Management Practices (Schueler, 1987), Water Sensitive Urban Design(Wong, 2006), Sustainable Urban Drainage Systems (Perales-Momparler, 2015), Low Impact Development (Prince & County, 1999).

Low Impact development aims to give an area its natural hydrology with land scaling and integrated control tools and establish the surface water flow, seepage, and evaporation amount before development with functionally equivalent hydrological services (Parry, 1998). LID methods can be easily applied to various scales and environments and have a large toolbox fed with nature-based solutions.

In the case of dense cities, integration of solutions to complex city networks, social structure, daily habits, and existing infrastructure can be challenging. Nature-Based Solutions (NBS) is an approach to taking nature to its centre to tackle environmental, social and management problems. The EU Research and Innovation Policy Agenda categorises the main goals of NBS: enhancing sustainable urbanisation, restoring degraded ecosystems, developing climate change adaptation and mitigation, and improving risk management and resilience (Bauduceau et al., 2015). For the subject of this thesis, NBS used for enhancing sustainable urbanisation. NBS have multi-benefits; therefore, not only for managing water but also for improving well-being and outdoor thermal comfort has been aimed (Xing et al., 2017). NBS requires comprehensive understanding and application for the maximised benefits for the environment and people.

There are many NBS applications worldwide, and their effects are widely searched and documented (https://una.city/). NBS are adequate to provide a sustainable and healthy ecosystem. Nevertheless, these systems require a broad, complex, and integrated understanding of many fields, including soil, water, economic and social and physical methods such as urban planning and architecture. The widely used control and treatment components are generalised based on their purposes, such as bioswale, rain garden and permanent surfaces (Perini & Pérez, 2018). When it's intended to use NBS for water management at the street-scale, many parameters need to be considered and create complex equations for the designers, decision, and policymakers. Although objective problems like the slope of the surfaces, thermal comfort, runoff amount or soil type increase the complexity, subjective approaches like context evaluations, architectural program proposals, land covers or evaluation of daily life in the area and future prospective make the problem not only context but also person dependent and add to the complexity of the situation enormously. With the help of environmental modelling, designers may have more control over their design spaces based on their performances and choices (Sang, 2020). However, the results coming from environmental models must be again interpreted by the designer. Without common ground on how to act and follow a procedure, designers may lose the inconsistency throughout the city.

The study is motivated by developing a design approach for integrating NBS for dense city environments at the street-scale for managing rainwater to achieve water-related goals such as improving the water cycle, controlling floods, or harvesting the water for reuse. By doing that, the approach also aims to improve the well-being of the habitants, enhance thermal comfort for all living, and increase biodiversity in the rea as secondary benefits. The challenge of the study will be accounting for qualitative and quantitative analysis within the same framework and give the designers and urban policy makers flexibility. So, the method will use both objective and subjective data. Moreover, by using already applied WM techniques and aiming for realistic projections included in EU Sustainability Goals, the author would like to create a road map for future applications for similar environments to the case area. The contribution of this paper to literature is a approach that will help designers develop water-sensitive nature-based solutions at the street-scale.

NBS is a trending topic due to its multi-beneficial impacts and low cost with well-planned applications for many challenges such as water management. Because of its wide range of application scales, not all the fields are thoroughly investigated from different aspects. Due to its initial instalment costs, primarily large-scale studies have been conducted. In this thesis, the author aims to examine NBS as its primary water management benefit to the city on the street-scale. Therefore, the main goal of the research is to investigate how WM treatments based on NBS can be considered street-scale mentioning with qualitative and quantitative data. In this respect, this research addresses the following questions.

1.2 Research Questions and Significance

The aim of the study is to develop a water sensitive early design approach for built environments with nature-based tools. This aim is supported by the following research questions:

- Can we develop a approach accounting for quantifiable and unquantifiable data to help designers and policymakers manage water with nature-based solutions at a street-scale to improve water cycle, flood resiliency and water harvesting?
- How can existing environmental simulations help developing a water sensitive design approach?
- How efficient are the secondary effects of nature-based solutions when they are designed for different purposes?
- How the integration of water management treatments would change the streets into more sustainable, resilient, livable environments?
- How the developed design approach can be applied to larger scale?

- How different stakeholders such as decision makers, policy makers, designers or habitants can use the developed early design approach to move towards water-sensitive built environments?
- How can this approach be integrated into planning policies and practices for present and future settlements?

In the light of aforementioned research questions, this research aims to contribute nature-based water management literature in the street-scale. Existing literature of applied nature-based solutions majorly focuses on larger scale such as water parks (The Gorla Maggiore Water Park Project (https://una.city/nbs/milano/gorla-maggiore-water-park)), resilient coasts (The C2C-CC Projects (http://www.c2ccc.eu/)) and urban drainage systems at city scale focusing on roads, roofs or yards (G.I.A.R.E. (http://www.giare.eu/)). Although there are tools that are being applied at street-scale, there is a gap at using applied systematic approach and advanced environmental simulation tools at street-scale. Moreover, the study aims to develop an approach that aims for street-scale with applicability to larger urban contexts which is another gap in literature. Therefore, the contributions of the study to the literature can be summarized as such:

- Scalable nature-based water management design approach starting from street-scale.
- Combination and integration of environmental simulations for a water-sensitive design approach
- Wide range of stakeholder awareness towards resilient urban ecosystems.

1.3 Research Methodology

The research methodology is based on three phases.

First, a critical overview of the literature on water management at a street-scale and nature-based water management solutions.

Secondly, a design approach is developed for the research to meet the questions asked above. Within the study, the method is explained step by step and then applied to an area specified in Ankara with its rich outdoor space qualities and urban morphologies to increase the complexity of the problem. The site is modelled accordingly, and environmental simulations are run to assess the current condition. Nature-based methods commonly used for water management are designated, and their specifications are introduced to the computational model for optimisation.

And thirdly, based on comparing the outputs of the simulations, future improvements, pros and cons of the design approach and secondary benefits of the NBS are stated.

1.4 Thesis Structure

Chapter II: Street-scale Water Management Strategies

Chapter II is a literature review on water management's theoretical and applied background starting from various scales. This chapter explains different water management aims and the focus scale.

Chapter III: Nature-Based Solutions for Water Management

Chapter III is a literature review on the theoretical and applied background of nature-based water management solutions. In this chapter, application areas and aims specified by United Nations are discussed and used, and documented methods for water management are explained.

Chapter IV: An Early Design Approach for Integrating Nature-Based Water Management Treatments into the Urban Context

Chapter IV is about explaining the parameters and process of design approachs. In this chapter, the authors explain how the procedure works and how it should be followed.

Chapter V: Case Study

In Chapter V, the design system is developed along with approachs for a specific street in Ankara. Afterwards, discusses and explains the comparison of existing and proposed conditions' environmental performances. It also discusses the framework, choices' effect, and secondary benefits.

Chapter VI: Conclusion

Chapter VI is the conclusion of the thesis, which summarises the research process, statement of limitations of the research and suggestions for future studies.

CHAPTER 2

STREET-SCALE WATER MANAGEMENT STRATEGIES

This chapter explains the need to develop a approach and why the street-scale is critical. It briefly explains the importance of water management at the street-scale and gives case studies worldwide to explain the need. Moreover, it will explain the current built environment with adverse effects on the ecosystem to address the issue more accurately for the case study and Turkish cities.

After stating the importance, it will explain the subgroups of problematic areas in our cities that we widely struggle with. These subgroups are also interpreted as different scenarios while developing the approach and explained wider in other chapters.

2.1 Water Cycle in Built Environment

Countries and local governments are increasingly considering the integration and promotion of sustainable infrastructure for water management for various reasons, including but not limited to rainwater harvesting, stormwater management and flood resiliency. The vicious circle started with developing water insensitive infrastructures and increasing the imperviousness of the city, lead the disruption of the water cycle, contaminated and declined underground waters and eventually change in the climate due to humidity changes in the air, increased urban heat island and biophilic effects of nature in our cities. Nowadays, we are under the threat of changing climate, worsening thermal conditions, water shortages, and crises in our cities (Pearlmutter et al., 2021).

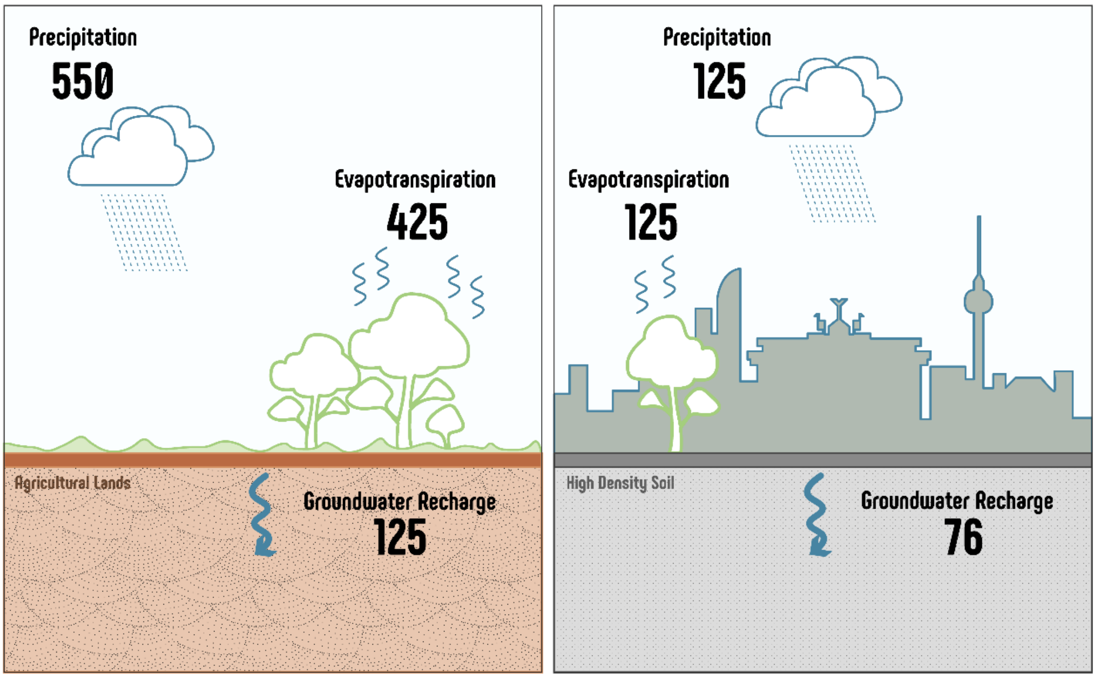

Figure 4. Schematic representation of change in water balance with urbanisation. (Pearlmutter et al., 2021)

As intended to continue developing these policies on larger scales, urban settlements and climate conditions at micro scales change more rapidly than the authorities and designers can keep up with. In larger-scale approaches, the system's inlet and outlet are calculated detailed, and mathematically the results are expected beforehand. Although street-scale treatments may be predicted to decrease flood scales and contribute to the general improvement of struggle with water management (Zellner et al., 2016), the unique condition of each neighbourhood makes it difficult to foresee with higher resolution and complicated to offer a generalised approach for all the parameters that a sustainable infrastructure system would require to be considered. Existing policies may examine the effectiveness of the selected water management method and attainable at the site scale. Still, they may not solve the spatial interactions, land cover and programmatic relations in the neighbourhood's context.

Therefore, developing a new approach for cities to embrace water management treatments at the street-scale requires a detailed analysis of qualitative and quantitative research and their unique combination supported by different scenarios, context analysis and the designer's unique interpretation.

The natural water cycle constantly recycles water via meteorological processes such as vaporisation, winds, condensation, groundwaters and runoffs. All the water passing through a surface is defined as surface water balance, and it's essential for urban water management. The circle affects many parameters such as heat, wind, amount of water and contamination of water. Cities drastically change the environment for the water cycle and disturb the process immensely (Oke et al., 2018). With installation systems to transport moisture through grey infrastructures, the natural water cycle was turned and interpreted as an urban water cycle.

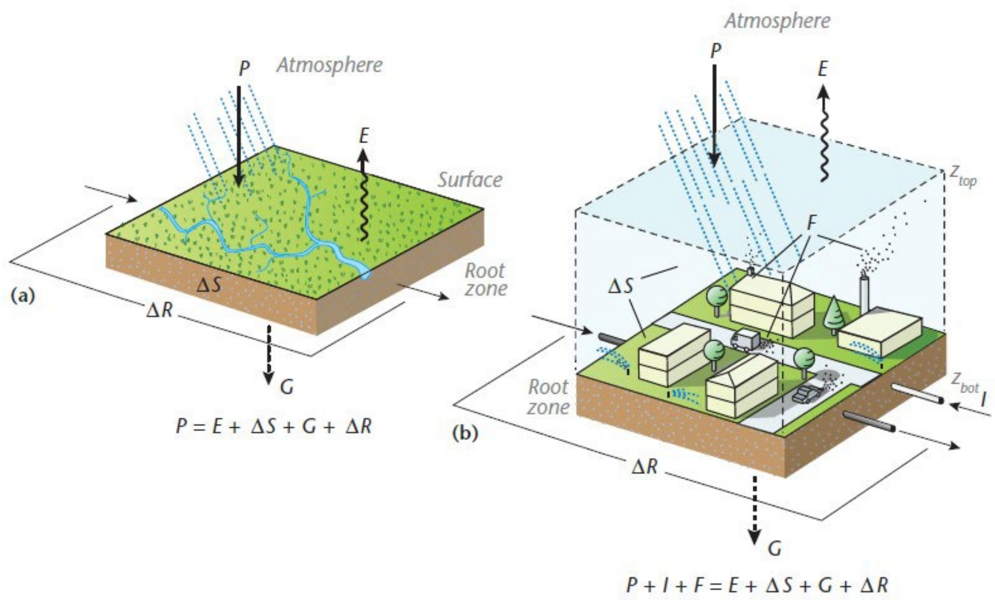

Figure 5 (a) Surface water balance and (b) the equivalent of an urban hydrological unit. (T. R. Oke, G. Mills, A. Christen, J. A. Voogt, 2018)

During urban development, water is treated as waste, and infrastructures have been built to collect and redirect it to the closest wetland or flowing water path. This system, combined with sewers and drainages, changes the infiltration area and eventually disrupts the water cycle by preventing the rain from infiltrating the ground as quickly as possible and contaminating the runoff water. Therefore, the soil generally fed with water and its necessary compounds starts to decay, lead holes underground, and cause collapsing of underground water holes.

The water cycle is affected by land use at macro and micro scales. For example, land cover changes can impact soils' ability to absorb surface water (infiltration). When soil loses its ability to drink water, rain that would otherwise infiltrate and contribute to groundwater reserves overflows, increasing surface water (runoff) and the risk of flooding. Deforestation can reduce soil moisture, evaporation, and rainfall locally, but it can also produce regional temperature changes, which impact rainfall patterns. Changing land cover can also affect the moisture content of the soil, affecting how rapidly the earth heats up and cools down, as well as the local water cycle. Drier soils lose less water through evaporation but heat more during the day. If there is enough moisture in the air, this can result in warmer, more buoyant plumes of air that can enhance cloud growth and precipitation. Land-use change, on a worldwide scale, is responsible for around 15% of carbon dioxide emissions from human activities, leading to global warming, which influences precipitation, evaporation, and plant transpiration. Furthermore, increasing carbon dioxide scales in the atmosphere because of human activities can make plants more efficient at holding water since the stomata do not need to open as widely. Improved land and water management (e.g., reforestation and long-term irrigation) can also help mitigate climate change and adapt to its adverse effects (Allan et al., 2021).

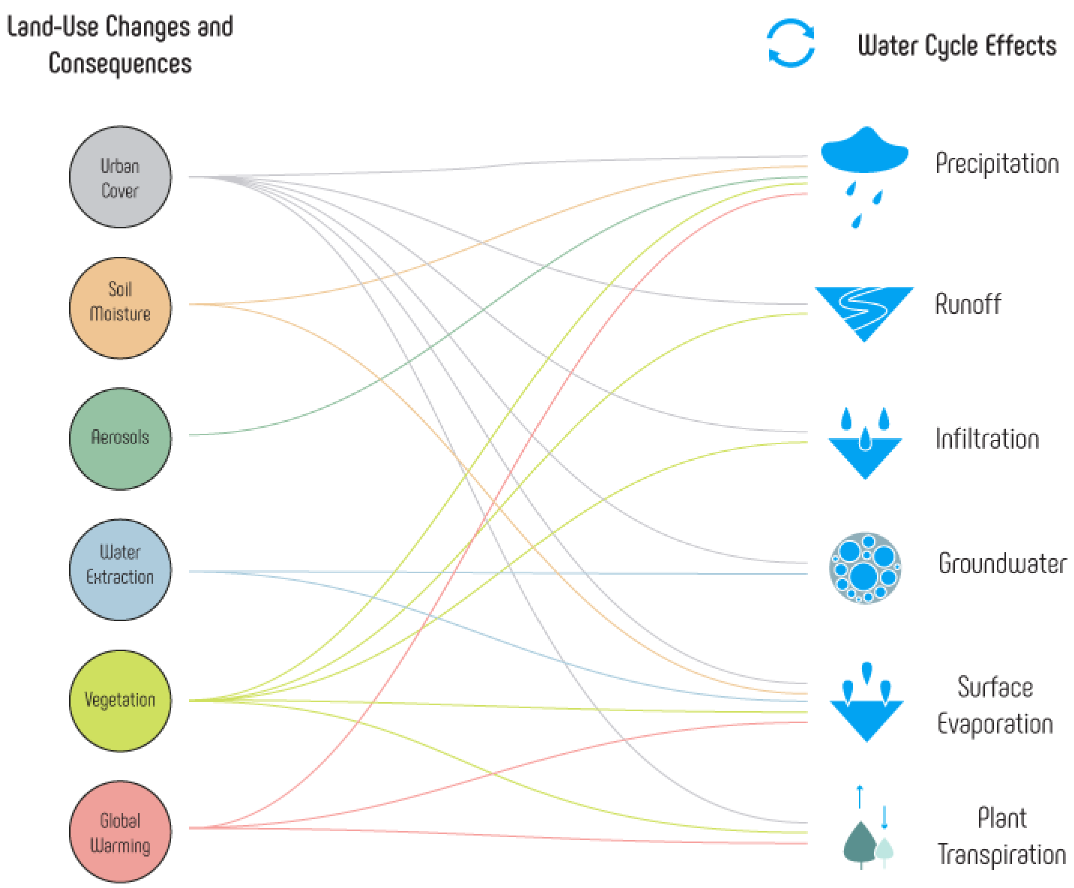

Figure 6 . Land-use changes and their effects on water cycle (Allan et al., 2021).

Unlike traditional systems, sustainable systems treat water as a source and meet with soil as quickly as possible. Urban areas support evapotranspiration via street trees and lawns, capture rain to reuse and increase the infiltration rate with more pervious surfaces (Grant, 2016).

2.2 Managing Water Cycle

This research discusses the water cycle under two specific categories to later deal with. Flood resiliency which occurs during specific times of the year and rainwater harvesting are the two important aspects where the water cycles are affected by. By discussing these problems under different headlines, thesis aims to develop problem-specific approaches.

2.2.1 Flood Resiliency

Floods are a natural and essential part of the water cycle, but they may threaten lives and safety without enough preparation and consideration. Most floods occur when water carrying paths (channels, rivers etc.) exceed their water holding capacity and overflow. Due to climate changes, rainfall events become more and more intense, and the frequency of floods increases. Moreover, fluctuations in wind patterns make some regions unusually wet or dry for a long time. That's also highly related to the disturbance of the water cycle locally (Allan et al., 2021).

Flooding chances increase when runoff is both greater in volume and flowing faster. Therefore, the main struggle to cope with flooding in built environments is infiltrating water as quick as possible to the ground and creating detention areas which can hold vast amounts of water when the infiltration is not enough and then slowly injecting that water back into the earth (Oke et al., 2018).

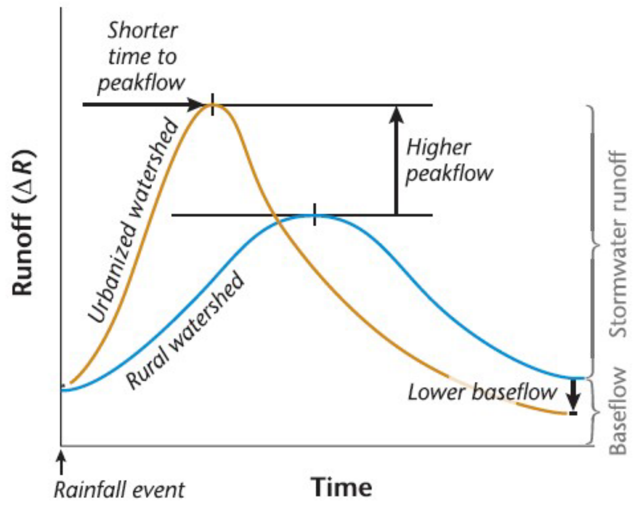

Figure 7. Typical storm hydrograph depicting the relation between stream discharge (Oke et al., 2018).

2.2.2 Rainwater Harvesting

Rainwater harvesting is a common and ancient practice of collecting and storing rainwater for use in residential and small-scale agricultural applications. RWH has been utilised in rural and urban areas, although its application in modern cities is limited. Nonetheless, there has been an increasing trend in recent years to use RWH in current urban areas as part of the solution to the expanding issues related to the supply of good quality water to the world population that is converging on cities. Given that urban development is unlikely to be halted due to water concerns, it is critical to guide urban planners on managing urban development while causing the least damage to groundwater resources (Vehicularmon et al., 1997).

The loss of infiltration and groundwater recharge due to the presence of large impervious areas, as well as changes in the pattern of surface runoff and river flow, are critical hydrological concerns in urban environments (Niemczynowicz, 1999).

In modern times, RWH was mainly based on collecting water from the rooftop and storing them in underground reservoirs or tanks. RWH is also a renewable source ideal for domestic and small-scale agricultural uses. With the increased population and water scarcity worldwide, countries tend to harvest water in infiltration wells which can also be used as rain gardens, bioswales or permeable pavements. These systems are connected via sewers to collect water at designated points to reuse for different purposes. To ensure efficient infiltration of harvested rainwater into the aquifer with no infiltration well system overflow, the infiltration well must be constructed sufficiently deep with a filter length long enough to allow adequately high-water flow from the well into the ground while taking into account the hydraulic properties of the medium at the specific infiltration site (Nachshon et al., 2016).

Like flood resiliency and the water cycle, the bottleneck of rainwater harvesting in the rapidly developing built environment is changing land use to impervious surfaces and increased runoff. Although water may not be harvested if the amount of water raining in the year is less, or the amount of water needed for domestic purposes is high, in both ways, capturing the water with pervious surfaces is essential for developing a rainwater harvesting method for the area (Chen et al., 2016).

2.3 Sustainable Urban Drainage Systems

A sustainable drainage system (SuDs) is a collection of practices and infrastructure meant to decrease the potential impact of new and existing developments on surface water drainage discharge. These techniques, which rely on natural processes such as evaporation, infiltration, and plant transpiration, can effectively and inexpensively supplement traditional "grey" infrastructure while providing various benefits. SuDS significantly reduce the amount of water entering local storm sewers or surface waters, reducing floods. Reduced stormwater runoff and pollution, as well as energy and water treatment costs, reduced flooding impacts, improved public health, and decreased damages to public infrastructure and associated repair costs, as well as injuries to private and public property, resulting in increased amenity values in urban areas.

Research (Jato-Espino et al., 2016) has been conducted on the causes of flooding in urban settings, including the sealing of urban surfaces, the Urban Heat Island Effect (UHIE), and the broader consequences of global climate change. Since SuDs have multiple benefits, are flexible, cost-efficient, and are widely used to address various problems. Due to their flexible and cost-efficient specifications, SuDs is easy to integrate into street-scales. Several researchers have put the comparison of different devices into tables to quickly analyse and apply at small scales (Perales-Momparler, 2015).

Among other water management systems, SuDs is more convenient to think within the technical and theoretical boundaries of nature-based solutions because it aims for increased infiltration, retention and filtration. Therefore, throughout the thesis, analysis or system developments are configured around the SuDs and benefitted from the sources mainly rely on tackling water-related problems on street-scale with SuDs.

SuDs	Flood Risk Management	Water Quality Management	Amenity and Biodiversity	Climate Change Mitigation	Landtake	Capital Cost	Maintenance Cost
Green Roof	++	++	+++	+++	NONE	***	**
Water Tank	+++	++	+	+	*	*	*
Water Tank	+++	++	+	+	*	***	**
Permeable Pavements	+++	+++	+	+	*	**	*
Bioretention	+++	+++	+++	+++	***	*	**
Rain Garden	+++	+++	+++	+++	**	*	*
Bioswales	+++	+++	+++	++	***	*	**

+ LOW CONTRIBUTION ++ MEDIUM CONTRIBUTION +++ HIGH CONTRIBUTION

* LOW COST ** MEDIUM COST *** HIGH COST

Figure 8. Benefits chart of some SuDs devices (Ashley et al., 2015)

CHAPTER 3

NATURE-BASED SOLUTIONS FOR WATER MANAGEMENT

This chapter explains the concept of nature-based solutions (NBS) and their application and tools in water management. The chapter discusses how to develop NBS and what makes a tool nature-based through the precedent cases and literature review. After introducing the concept, the chapter will discuss the goals within NBS and effective integration into cities. Selected treatments based on goals and future directions will be explained in detail and supported with research and discussion application areas. Lastly, the co-benefits of NBS will be presented and discussed. Although the primary concern in this study is managing the water in built environments, the co-benefits of NBS is not disvehicularded and included in the evaluation and comparison phases.

3.1 Developing Nature-Based Solutions

Nature-based solutions are approaches that reverse ecosystem degradation and address societal challenges while also benefitting human well-being and biodiversity. Concerning urban green and blue spaces, nature-based solutions (NBS) can foster and simplify implementation actions in urban landscapes by considering the services provided by nature (Secretariat of the Convention on Biological Diversity, 2009). Examples of NBS include providing urban green such as parks and street trees, which may ameliorate high temperatures in cities (Castleton et al., 2010). Furthermore, architectural solutions for buildings, such as green roofs and wall installations for temperature reduction and related energy savings through reduced cooling, can contribute to NBS. Integrating NBS in urban landscapes makes multiple benefits related to climate change adaptation and mitigation increasingly recognised as influential determinants of human health and well-being (Hartig et al., 2014b). Hence, it enhances the current situation with and by nature (Kabisch et al., 2017). In principle, NBS promotes concepts like green infrastructure and biodiversity. NBS has been effectively used in dealing with thermal comfort in various studies (Sjöman, 2020; Yahia et al., 2018; Yahia & Johansson, 2014). Using natural landscape elements such as trees, bushes, green surfaces, and biological ponds shows similar benefits to previous research in terms of thermal comfort and increased biodiversity (Hassall, 2014; Jasmani et al., 2017; Nordh et al., 2009). To tackle serious economic, social and environmental challenges, efficient research and innovation should be done by co-designing knowledge and implementation as a result of an iterative process involving designers, policymakers and researchers. According to sta udy, the designer rarely uses the published evidence (2.1% of decisions) (Sutherland et al., 2004) for various reasons such as short of paywalls, limited time and extracting practical inputs from academic publications. When research findings are presented appealingly, people's decisions are more likely to alter (Walsh et al., 2015).

The mismatch between policies and evidence is a severe problem. The approach breaks down the broad goals into specific interventions (Pullin et al., 2009). For instance, the overall goals of greening cities to reduce pollution and noise and improve health and investment will be achieved through various interventions, including tree planting to reduce air pollution, green roofs and walls, attractive green spaces for exercise, and the restoration of derelict land. Green roofs, for example, can be created in various ways. The evidence can determine the most cost-effective means of delivering these (Bauduceau et al., 2015).

In a study conducted by EU Research and Innovation Policy Agenda (Bauduceau et al., 2015), evidence-based NBS has been addressed with three critical issues:

1. Is the recommended solution successful in resolving the issue? How efficient is tree planting, for example, in lowering air pollution? What are the differences between tree species? What are the differences between the various spacing patterns?

2. What are the most efficient ways to set up and manage a green solution? For example, what is the success rate of various methods for building green roofs?

3. How does the effectiveness alter when the environment changes? Many will differ depending on the climate, local ecosystem, or socioeconomic differences. (Bauduceau et al., 2015)

The task then becomes to review the evidence methodically, assess its relevance and quality, and make it available to practitioners.

There is a real risk that significant amounts will be spent on ineffective operations if this evidence base is unavailable. Similarly, the success of agri-environment projects, for which €24 billion was invested between 1994 and 2002, was varied, with 6% showing declines, 23% leading no change, and 17% offering a mixed (Yahia et al., 2018). Ineffective bat conservation interventions (Jasmani et al., 2017; Nordh et al., 2009; Sjöman, 2020), ineffective amphibian habitat management in the United States (Hassall, 2014; Sutherland et al., 2004; Walsh et al., 2015), and ineffective government wood harvesting standards for conserving the Siberian flying squirrel (Pullin et al., 2009) are some other instances.

Again, from the same study (Bauduceau et al., 2015), the best practice to assess evidence is based on four stage process.

1. The first step should be to compile a list of potential interventions to be as thorough as possible (Sutherland et al., 2014). These should be detailed, such as a list of all conceivable ways to reduce flood risk through land management improvements.
2. Interventions must be prioritised based on their potential for implementation; for example, those relating to metropolitan areas are likely to be prioritised.
3. The published literature must be reviewed systematically and objectively, with the evidence's relevance and quality assessed. It is necessary to

determine how local environmental or social conditions modify efficacy to generate local solutions to local conditions.

4. The findings should be synthesised and provided to practitioners in a way that allows a wide range of people to use them, such as through existing websites. As a result, an online resource will be created to suggest evidence-based practice for various interventions under various scenarios. (Bauduceau et al., 2015)

The questions and evidence-based development of NBS create a solid ground for having practical implementations with subsequence actions and can be systematically assessed within existing initiatives. For the process with multi-stakeholder engagement, design and performance should be accompanied by scientifically sound knowledge.

3.2 Aiming for Sustainability Goals with Nature-Based Solutions

Actions inspired by, supported by, or imitated from nature are nature-based solutions. They have enormous potential to be energy and resource-efficient and change-resistant, but they must be tailored to local conditions to be effective. They can contribute to green growth "future-proof" society, boost citizen well-being, provide corporate possibilities, and position Europe as a global leader by addressing several social concerns in sustainable ways. Natural solutions offer many co-benefits to health, the economy, society, and the environment, making them more efficient and cost-effective than traditional ways. EU Research and Innovation Policy Agenda identify four main goals that NBS can address:

1. Enhancing sustainable urbanisation by stimulating economic growth while aiming for an improved environment, more attractive cities and enhancing human well-being.
2. Restoring degraded ecosystems by delivering essential ecosystem services while meeting other societal challenges.

3. Developing climate change resiliency and efficient carbon storage.
4. Improving risk management with multi-beneficial tools of NBS.

Seven NBS alternatives for research and innovation actions are offered for the European Commission and the Member States to pursue based on the four aims.

1. Regeneration of urban areas
2. Improving well-being in an urban context
3. Coastal resilience development
4. Watershed management and ecosystem improvements
5. Sustainable use of the matter and energy
6. Ensuring the value of ecosystems
7. Better carbon sequestration.

This study uses this research and innovation actions as an initial point to form the base strategy of focusing on street-scale in built environments to use NBS effectively. In that regard, two actions are prioritised and focused on: urban regeneration and improving well-being in urban areas while contributing to sustainable use of matter and ensuring ecosystems.

3.2.1 Urban regeneration through nature-based solutions

Many cities face land cover changes, neglected land, and abandoned places. The context for new green growth initiatives is provided by urban regeneration through nature-based solutions.

For example, nature-based solutions are essential in supporting green, blue, and grey infrastructure development and optimisation. Green infrastructure may help reduce energy and resource demands and costs by providing cooling and insulation, reducing the urban heat island effect, and reducing the need for heating and air conditioning through green roofs and green walls (Pérez et al., 2018). Land cover changes, neglected land, and abandoned areas are all difficulties that many cities confront. Urban regeneration through nature-based solutions provides the backdrop for new green growth initiatives. Nature-based solutions, for example, play a critical role in creating and optimising green, blue, and grey infrastructure. Architectural scale components of green infrastructure, such as green roofs and green walls, can assist decrease energy and resource demands and costs by providing cooling and insulation, minimising the urban heat island effect, and reducing the need for heating and air conditioning.

Many cities face land cover changes, neglected land, and abandoned places potential sites for green growth projects through nature-based solutions. The Promenade Plantée in Paris, which was created by converting an elevated freight rail line into a park, and ideas for using underground space for underground parks in New York (*The High Line*, 2000) are certain precedent cases. Converting abandoned land into urban farms and communal gardens, bioremediation of toxic soils and subsequent transformation of former industrial sites into green space, provide opportunities for sustainable urban expansion. One of many instances is Milan's, Parco Nord.

Efforts to find and implement nature-based solutions may also lead to a re-examination of cities' economic foundations and opportunities for companies to innovate to redevelop abandoned urban and periphery regions. This might lead to new business models motivated by city sustainability concerns and divorce economic growth from resource degradation and unequal resource distribution. Cities may act as test beds for natural-based solution discovery, experimentation, and evaluation, to maximise a variety of environmental, social, and economic co-benefits for everybody. Existing municipal networks can make it easier to replicate sample initiatives and scale up intervention capacity.

3.2.2 Nature-based solutions for improving well-being in urban areas

The potential implications of development decisions are unsurpassed, with millions more needing homes, services, workplaces, infrastructure, and institutions.

Increasingly, dense cities may promote human health and well-being while providing ecological and economic advantages by incorporating nature-based solutions into urban architecture and planning.

According to a growing body of studies, access to green areas and a high-quality environment has improved health, well-being, social cohesion, and community support. Using nature-based solutions to improve neighbourhood spaces can encourage healthy physical activity and forming social relationships since individuals are drawn outside to use public areas together and feel safer walking around freely in more significant numbers (Coley et al., 1997). Even a permanent 1% reduction in the UK's sedentary population might result in annual economic advantages of up to £ 1.44 billion, or £800 per person, in the form of social benefits and reduced health risks (Callaghan et al., 2021). The issue for urban planners in the future will not be squeezing the most out of space but squeezing the most out of the experience of urban living and green areas, both of which may contribute significantly to creating a more liveable urban environment (Hartig et al., 2014). As a result, sample projects are needed to illustrate how nature-based solutions' various social advantages and other benefits may be most effectively realised through the systemic integration of nature-based solutions into urban design.

Urban planners must encourage space and service flexibility while simultaneously encouraging change via adaptability and innovation. This necessitates rethinking the natural and constructed environments, authorities' and people's mindsets. Those working to create healthy environments, such as public health specialists and landscape architects, already see urban greening as a valuable asset with huge potential for improving health and well-being (Bull et al., 2013). The quest for locally appropriate nature-based solutions will create a setting for these experts to investigate the flexibility of places and services, stimulating change via adaptation and creativity. Nature-based solutions tend to be popular among urban residents, and citizen empowerment and citizen-driven innovation are critical to realising the potential advantages of nature-based solutions for social regeneration in cities. New stakeholder engagement and citizen participation in urban design and planning must be developed to harvest these creative talents, resources, and collaboration.

3.3 Nature-Based Water Management

Rather than conventional developments, nature-based water management treatments use water as a source for the water cycle and recharging underground waters. While traditional methods favour drains and hidden pipes to remove rainwater from the area as quickly and efficiently as possible, nature-based treatment methods focus on reducing runoff and redirecting water either infiltrating into the ground or evaporating within a decentralised system. Nature-based treatments can either delay the infiltration of water to the ground within bioswales, rain gardens to sanitise water during heavy rains, or directly infiltrate to the ground within pervious surfaces.

There are many attempts to categorise nature-based treatments under different conditions. Local governments in San Mateo County, California, agreed to create the Sustainable Green Streets and Parking Lot Design Guidebook to decrease water contamination caused by stormwater runoff. Designers, builders, municipal officials, and other interested parties in the county have used the guidebook to get practical, up-to-date information (Sabbion, 2018).

Urban Conditions	Vegetated Swale	Stormwater Planter	Curb Extension	Pervious Pavers	Green Gutters	Rain Garden
Low-Density Residential	*	*	*	*	*	*
High-Density Residential		*	*	*		
Commercial Main Street	*	*	*	*	*	*
Arterial and Boulevard	*	*	*		*	
Parking Lots	*	*		*	*	*

Figure 9. Stormwater treatments that fit for various urban conditions (San Mateo County and Nevue Ngan Associates, 2009).

In another study in which researchers measured the suitable green streets and performance based on LID qualifications, nature-based treatments were evaluated in terms of their effect on runoff volume, peak flow, recharge of groundwater and reduction of pollutants (Sabbion, 2018).

Stormwater Management Measure	Reduction in Runoff Volume	Reduction of Peak Flow	Recharge of Groundwater	Reduction of Pollutants
Stormwater Tree Trench	+	+	++	++
Infiltration Trench	+	+	+	++
Vegetative Buffer Strip	+	+	+	+
Bioswale	+	+	+	++
Rain Garden	++	++	++	++
Stormwater Basin	-	++	++	+
Stormwater Wetland	-	++	-	++
Private Garden/Landscaping	++	++	++	++
Permeable Pavement	++	++	++	+

++ VERY EFFECTIVE + EFFECTIVE - NO IMPACT

Figure 10. Nature-based stormwater management measures (Sabbion, 2018).

In addition to subjective analysis on applying treatments to specific conditions, new tools are being studied at Harvard and Cambridge Universities based on land cover performance analysis (Chen et al., 2016). In that research, a new tool for urban rainwater management was proposed for architects and designers to use in the early design phases. Based on the calculations (Natural Resources Conservation Service,

1986) and existing conditions performances, an approach for runoff evaluation and management has been proposed. The terrain is also considered and evaluated as a source of deciding on methods but not based on statistical inputs.

Table 1. Land cover description and curve numbers (Chen et al., 2016).

	Curve numbers for hydrologic soil group			
Cover Description	A	B	C	D
Lawn poor condition (grass cover <50%)	68	79	86	89
Lawn fair condition (grass cover 50%-75%)	49	69	79	84
Lawn good condition (grass cover >75%)	39	61	74	80
Roof	98	98	98	98
Paved parking lot	98	98	98	98
Paved (curbs and sewers)	98	98	98	98
Paved (open ditches)	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Newly graded areas	77	86	91	94

The most critical components of the new sustainable approach to stormwater management are urban trees and hedges, pocket parks, rain gardens, and bioswales. They tend to integrate green and blue infrastructure within urban planning, shifting from traditional control solutions to new approaches focused on local collection and distribution, slower flows, and increased permeability. In a context-adaptive process, green streets can include soil, vegetation (trees, shrubs, and herbs), permeable pavements, and engineered systems to construct more sustainable roadways, parking lot, and sidewalk surfaces (Sabbion, 2018).

Based on being applicable, measurable and their effects studied on literature, several methods have been chosen to be evaluated and included in the proposed design approach in this study. Processes managing water from roofs or vertical systems such as green roofs and green walls had been excluded due to the thesis’s focus on land cover. Among many methods, vegetated buffers (lawns), porous surfaces, street trees, rain gardens and bioswales have been compared and evaluated. These methods have similarities and specific differences that can be adapted to different conditions. Moreover, these methods are open to interpretations during the design and application phases. For example, bioswales can be designed as either vegetated or non-vegetated depending on the scenario or turned into vegetative buffer strips when placed alongside roads or parking lots to treat runoff.

The next subchapters discuss the different features of each tool that are aimed to use while developing the design approach.

3.3.1 Pervious Surface

Porous pavement comprises a permeable surface (pervious asphalt, concrete, or pavers), a granular foundation, and subbase elements that enable drainage to penetrate the soils beneath it.

The effectiveness of alternative pavement systems is determined by whether the pavement is designed to retain and permeate the majority of runoff, or merely a small amount of runoff (e.g., "first-flush"), with the rest released to a storm drainage system or overland flow. Long-term usage and efficacy necessitate maintenance. Pavement options vary in load vehicular capacity, although they are typically suitable for low-traffic locations such as walkways, parking lots, overflow parking, and residential roads. It is critical to select a material acceptable for the intended application.

A typical porous asphalt, block pavers, plastic grid paver course, a filter course, a reservoir course, a geotextile filter fabric, and existing soil or subbase material make up a specific permeable pavement option. Some materials will be more resistant to their intended usage and site circumstances than others; thus, choosing a paver type should be considered (*Maine Stormwater Management Design Manuel*, 2016).

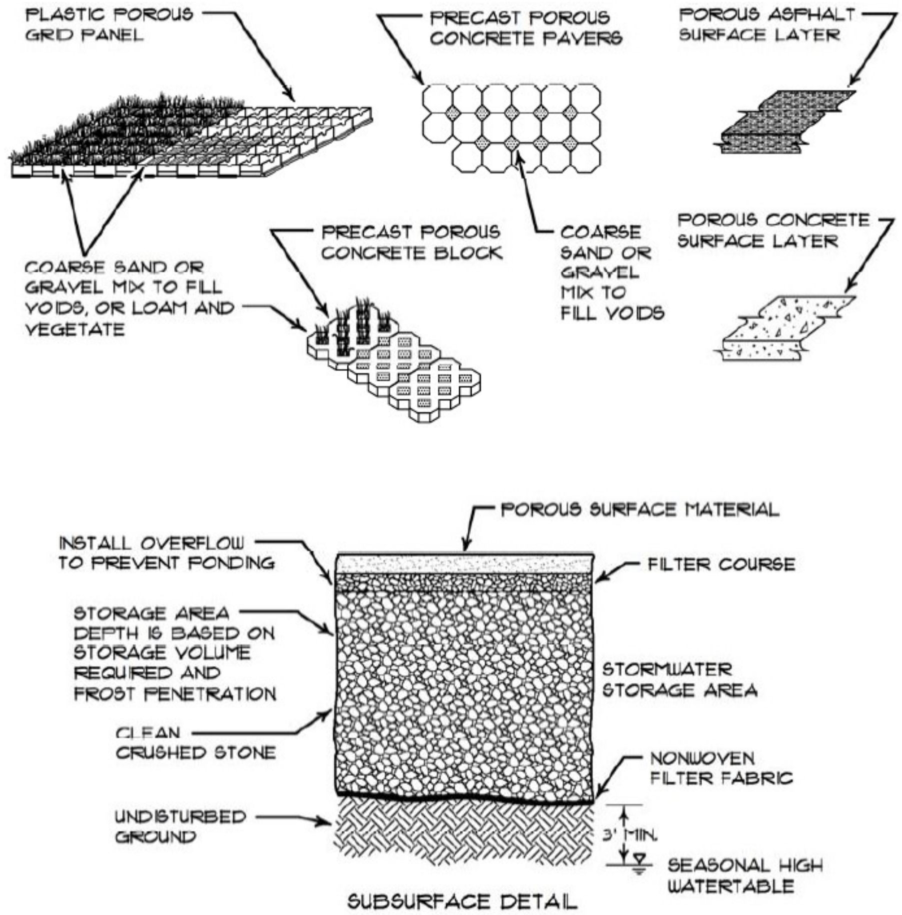

Figure 11. Types of Pervious Pavement (*Maine Stormwater Management Design Manuel*, 2016).

3.3.2 Vegetated Buffers

Buffer strips are natural, undisturbed sections of natural vegetation near and downslope developed regions or planted strips of close-growing vegetation. Vegetation and the organic duff layer restrict stormwater runoff as it passes through the buffer zone, trapping particle pollutants and enabling time for penetration. When developed in line with this document, buffers can also be used to remove phosphorus. The following factors of the effectiveness of buffers for pollutant removal: buffer length, slope, scale spreader berm length (if needed), organic duff layer thickness and structure, mineral soil structure, including consistency, bulk density, and depth to restrictive layer or seasonal groundwater table, drainage area size, and vegetation type and thickness (resistance to overland flow).

Vegetated strips mitigate stormwater runoff impacts by collecting sediment and sediment-bound contaminants, providing some infiltration, delaying and spreading stormwater flows over a large region, and safeguarding sensitive areas.

3.3.3 Street Tree

Planting trees is a crucial strategy among various natural stormwater management strategies. Trees intercept rainfall, evapotranspiration, and a significant quantity of water from the soil and improve penetration.

Furthermore, trees may benefit in tight urban environments since they perform crucial tasks while taking up little space. Trees serve as water reservoirs, absorbing and filtering rainwater. Canopy interception loss, transpiration, and better infiltration are all consistent advantages supplied at various times: canopy interception is essential during a storm event, whereas transpiration performance continues in the time between rain events (Berland et al., 2017).

Depending on the water collected and seasonal tree variations, tree species can determine varying canopy interception rates. For broadleaf forests, the interception loss can be as high as 18 per cent to 29 per cent of total rainfall; coniferous forests can be as high as 18 per cent to 45 per cent (Berland et al., 2017). Conifers may retain more water on their leaves and stems than broadleaf trees, according to a study that looked at the surface water storage capacity of 23 Californian species (Xiao & McPherson, 2016). Furthermore, surface interception differs significantly across species with distinct properties. Fagus grandifolia, for example, can intercept 500 L on average for every storm event, whereas Liriodendron tulipifera may intercept 650

L (van Stan et al., 2015). It's crucial to consider how trees interact with stormwater in various geographic and climatic settings and the leaf-on time and storm event season.

3.3.4 Rain garden

A rain garden is a slight depression filled with absorbent yet free-draining soil and flora that can endure brief floods. Rain gardens are created to replicate the natural water retention of undeveloped land, as well as to limit the amount of precipitation that runs off into drains from impervious areas and remediate low-scale pollutants. Our towns and cities have large sections of sealed surfaces, such as roofs, pavements, and roadways, which present challenges. When it rains, water usually flows directly into drains, which can become overburdened during storms. Localised flooding might result because of this, causing property damage and clogging roadways. Sewage can enter watercourses and streets in some cities where surface water drains and filthy sewers are linked. Even if flooding does not occur, runoff can vehicular oil, heavy metals, and other contaminants into waterways, causing harm to aquatic plants and animals. During the summer, sealed surfaces might be problematic. More heat is absorbed when the sun shines brightly, making cities hotter than the countryside.

Rain gardens can be placed in sunny or shady regions of your lawn. Still, plants should be chosen accordingly, with the lowest point planted with wet tolerant species, the sides closest to the centre planted with moist susceptible species, and the edges of the rain garden should be planted with suberin (damp to dry) or xeric (dry) tolerant plants. Overall, once plants mature, the maintenance of a rain garden is typical of any other landscaped area. Watering is essential during the first growing season, and some weeding is necessary after planting. As the garden matures, some perennials may need to be divided if plantings become too crowded (Bray et al., 2015).

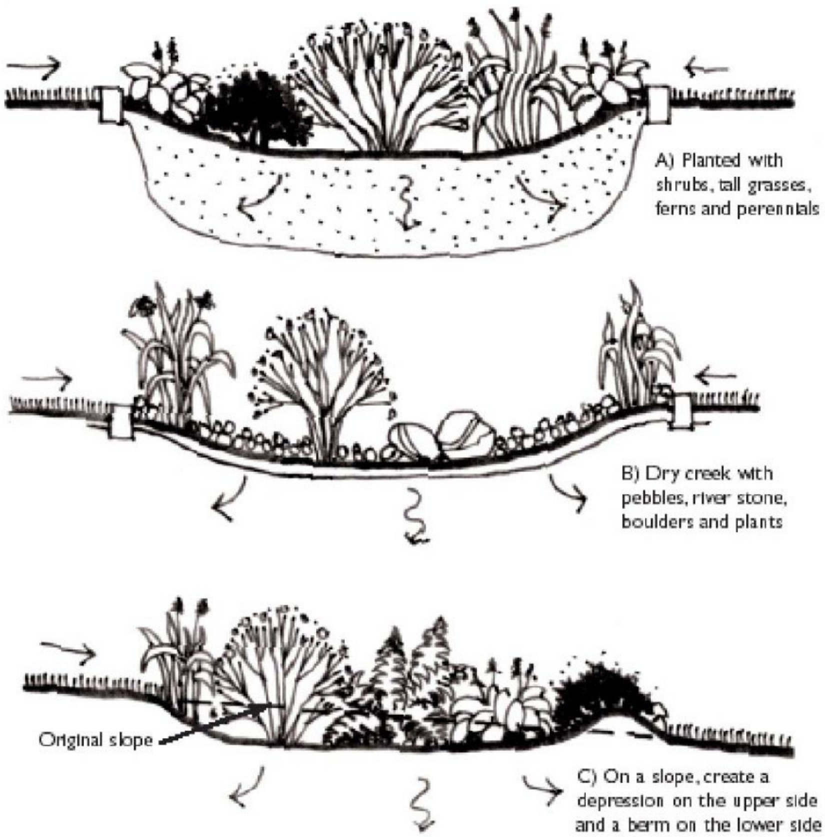

Figure 12. Diagram showing various rain garden configurations (*Maine Stormwater Management Design Manuel*, 2016).

3.3.5 Bioswale

Bioretention is a natural, aesthetically beautiful urban stormwater BMP that reduces runoff and improves quality. It's part of the LID concept, which uses microscale stormwater retention and infiltration tracts across built regions.

Bioretention typically comprises a porous media that supports a vegetative layer and a hardwood mulch layer on top. During and after rainstorm events, a ponding area acts as a reserve place for runoff storage and gives more time for water to permeate into the medium. As communities grapple with the ecological implications of urban expansion, bioretention and other LID strategies are gaining traction. Several studies have shown that the bioretention idea is moderate to highly successful in removing contaminants from entering runoff (Davis et al., 2003).

Physical filtration and adsorption are combined with biological processes in this approach. The system may include a grass channel input pre-treatment filter strip, a shallow surface water ponding region, a bioretention planting area, a soil zone, an underdrain system, and an overflow outlet structure (Prince & County, 1999).

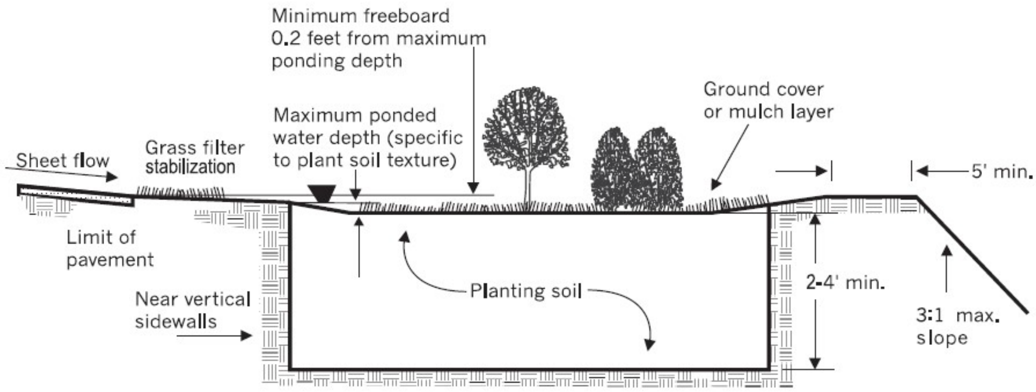

Figure 13. Typical bioswale detail (Prince & County, 1999).

3.3.6 Building Scale Treatments

Building scale elements, mainly vertical greenings and green roofs help close the water cycle by covering the vertical elements of buildings and roofs. A roof is an ideal building component to collect direct rainwater and redirect it to storage elements or directly to the ground. By integrating green roofs, the harvesting capacity and filtration time can be increased to deal with rainwater harvesting and flood control up to some points; however, the collected water must be transmitted to the ground at the final stage, or the vegetation on the roof must be designed so that collected water can be used for irrigation. Vertical green elements both slow down the rainwater and helps to manage through a drain and transmit the rainwater like a green roof. Moreover, these techniques are essential for dealing with urban heat islands. Nevertheless, within the scope of this thesis, building scale elements are not included in the approach as they are not dependent on the urban context and can be implemented if the roof's condition and the building's structure are sturdy enough. Building scale elements are essential tools and should be considered, especially during the early phases of the design process of structures, and structures should be designed accordingly.

3.4 Co-benefits to Ecosystems with Nature-Based Solutions

Nature-based solutions show great benefits aside from their major implementation reasons. Apart from managing water quantity and quality, they can also store carbon, increase pollination and biodiversity, improve air quality and regulate microclimate in terms of cooling and heating, depending on the case. Other than its ecosystem benefits, in the application process, they provide the ecosystem with stable jobs for the community's future, indirectly support other economies such as health and increase the well-being of the people around (Bauduceau et al., 2015).

The best schemes incorporate a range of habitats beneficial for wildlife and water management bringing urban wetlands and other wildlife-friendly green spaces into our towns and cities. With careful siting, they can link existing habitats to create green corridors with improved habitat connectivity.

With careful planning, many habitats within the city can be linked to improving the ecosystem in many aspects. Treatments with vegetated surfaces such as green roofs, walls, rain gardens and buffers can attract species with local and rich plant varieties to feed, breed and accommodate for various seasons, including insects and birds. Moreover, these plants store vast amounts of carbon while growing while planned accordingly and require minimum water to sustain themselves when they are selected accordingly. Connecting these areas in the city enables linked ecosystems to increase and attract more species. Ecosystem bridges are designed so that links can be made. Vegetated areas can filter pollution both from water and air. Street-scale filtering can prevent the accumulation of pollutants in wetlands and rivers.

3.4.1 Improving Outdoor Thermal Comfort

The city's environmental conditions affect human health and quality of life. Phenomenon like Urban Heat Island (UHI) can cause higher temperatures in cities compared to rural areas. UHI is mainly related to (Oke et al., 2018):

- Manmade surfaces ratio in cities.
- Human-based heat sources (air conditioning, industry, transportation)
- Decreased evaporation due to impervious manmade surfaces.
- Dense city morphology which changes wind speed and creates canyon effects.

Studies show that greenery highly affects microclimate due to evapotranspiration, shading time and mean radiant temperatures (Onishi et al., 2010). A study (Givoni, 2009) asserts that lower wind speeds, higher mean radiant temperatures brought on by sun access, and higher temperatures brought on by the UHI phenomena during the summer are the leading causes of thermal discomfort in urban areas. The situation is reversed in winter circumstances, though. For instance, solar radiation may significantly boost outdoor comfort during the winter while significantly decreasing it during the summer.

The thermal equilibrium between the human body and the environment determines thermal comfort. Measurement techniques are crucial because this is a subjective impression. The projected mean vote (PMV), physiological equivalent temperature (PET), standard effective temperature (SET), and universal thermal climate index are the most used indicators among these (UTCI). Fanger's (1973) PMV, which he invented, views comfort as the thermal equilibrium of the surroundings and boundary conditions. The occupants' sense of heat stress or cold is reflected in SET. PET (Höppe, 1999) contrasts challenging outside circumstances with a typical steady-state interior environment (Gagge et al., n.d.). The dynamic physiological response model-based index UTCI was just created (Bröde et al., 2010). This thesis focuses on UTCI, the newest developed index to predict human thermal comfort in outdoor spaces, since UTCI's focus area is large, and the idea does not focus on specific subject groups.

Climatic and environmental functions of NBS can help regulate microclimate by adjusting solar radiation transmission ad reducing or increasing airflow, directly affecting the well-being of people at doors and encouraging people to spend more time outdoors and efficiently incorporate these spaces to people's daily routines.

Characteristics of natural elements determine outdoor comfort performances depending on various factors such as season, climatic conditions and urban morphology, which affects radiation and wind directly (Bauduceau et al., 2015).

Bauduceau, explains the main characteristics of vegetation affecting outdoor comfort parameters are shown in Table 2. Main Characteristics of Vegetation Affecting Outdoor Comfort Parameters..

Table 2. Main Characteristics of Vegetation Affecting Outdoor Comfort Parameters.

1. Foliage shape and dimension
    a. Regarding mean radiant temperature, foliage determines shadow area, depending on the site latitude
    b. Row/group of trees can create a barrier or increase air flow.
    c. Foliage affects plants evapotranspiration, which results in reduced air temperatures and increased air humidity.
2. Height of trunk
    a. Regarding mean radiant temperature, the trunk's height determines shadow area, depending on the site latitude.
    b. In order to protect itself from winter wind, the trunk's height should be reduced.
3. Leaf area density (LAD)
    a. High values reduce the solar radiation transmitted during summer.
    b. LAD determines the air flow through the foliage (low or high)
    c. LAD affects plants evapotranspiration, which results in reduced air temperatures and increased air humidity.
4. Seasonal cycle
    a. Deciduous plant species avoid winter shading.
    b. Evergreen species are required for winter air flow control
5. Daily transpiration
    a. High levels of daily transpiration cool the air flow passing through trees.
    b. Transpiration implies a thermal energy absorption able to decrease summer overheating and increase air humidity.

To quantify the effects of greenery on outdoor comfort, environmental modelling and analysis tools can be used. Compared to other tools, CitySim Pro, RayMan, and the Grasshopper plug-in Ladybug tools, ENVI-Met stands out with significant benefits, including accounting for longwave radiations and diffuse radiations and local wind speed and direction (Naboni et al., 2017). These are crucial variables, particularly when computing mean radiant temperature, because it directly influences UTCI. ENVI-Met is a prognostic, three-dimensional, grid-based microclimate model developed to simulate complicated surface-vegetation-air interactions in the urban environment. The software uses a 3D atmospheric model to simulate air temperature and humidity (Skelhorn et al., 2014), wind speed and direction (Herrmann & Matzarakis, 2012), turbulence, short- and long-wave radiation fluxes, as well as the dispersion and deposition of contaminants. Since the software can incorporate several inputs, it primarily focuses on evaluating air temperature, mean radiant temperature, and surface temperature (Lobacvehicularo & Acero, 2015).

Due to its significant relevancy with NBS, outdoor thermal comfort is considered a significant secondary benefit while considering the treatments and included during the approach creation processes as an essential parameter. By considering outdoor thermal comfort as an important asset, this thesis aims to develop a tool aware of their multi-benefits and integrate them during their framework.

CHAPTER 4

AN EARLY DESIGN APPROACH FOR INTEGRATING NATURE-BASED WATER MANAGEMENT INTO THE BUILT ENVIRONMENT ON STREET-SCALE

Chapter 4 explains the method of creating a design approach for the problem mentioned above our cities face today. Concluding the initial deductions from water management at street-scale, which require designers, and decision-makers to investigate city context creates a necessity for an environmentally sensitive approach at street-scale. This approach classifies the treatments under further analysis and scenarios with an integrated qualitative and quantitative approach. It explains the classification of treatments under different analyses, which are thermal comfort, runoff, building proximity and slope. This matrix is used during the approach and weight distribution for other purposes.

In Chapters 2 and 3, a literature review of water management strategies, nature-based solutions, their secondary benefits and integrated urban water management is discussed, and critical points are identified. The following deductions are made based on the literature review.

- Cities are growing at an unprecedented pace and without long-term and context-aware water sensibility. The general tendency is to apply the easiest and low-cost technologies that are available at the time.
- Lack of water management causes environmental, economic and social damages at various scales.
- Nature-based solutions may help to decay the fading of ecosystems from our cities while responding to primary issues such as water management.

- The knowledge gap exists in developing an automated approach for cities at the street-scale. Although various intervention scenarios are prepared for the largest scales, due to their complexity, it is unrealistic and ineffective to propose a method for street-scales.
- Using nature as a tool may contribute to other ecosystem problems such as loss of biodiversity, decreased urban heat island effect, reduced noise, improved air quality etc. Therefore, the side benefits of nature-based solutions should be considered beforehand and taken as a parameter while answering the gap in street-scale integration of water management treatments.

The approach aims to be followed by designers who are in the early stages of the design process and makes deductions from their analysis of the site and policymakers who are about to make decisions regarding the future development of the area and further work distribution. Either way, the study aims to help integrate context-based variables into the thinking process and lead to an environmentally aware process.

People who would like to follow the approach should have the basic knowledge of data acquisition from different platforms, basic three-dimensional modelling, existing plan drawings of the site and any program that may help them analyse environmental conditions such as thermal comfort and water runoff.

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- Nature-based solutions may help to decay the fading of ecosystems from our cities while responding to primary issues such as water management.
- The knowledge gap exists in developing an automated approach for cities at the street-scale. Although various intervention scenarios are prepared for the largest scales, due to their complexity, it is unrealistic and ineffective to propose a method for street-scales.
- Using nature as a tool may contribute to other ecosystem problems such as loss of biodiversity, decreased urban heat island effect, reduced noise, improved air quality etc. Therefore, the side benefits of nature-based solutions should be considered beforehand and taken as a parameter while answering the gap in street-scale integration of water management treatments.

The approach aims to be followed by designers who are in the early stages of the design process and makes deductions from their analysis of the site and policymakers who are about to make decisions regarding the future development of the area and further work distribution. Either way, the study aims to help integrate context-based variables into the thinking process and lead to an environmentally aware process.

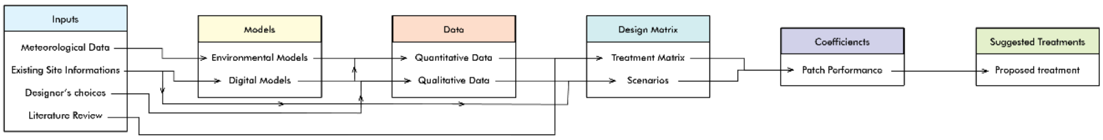

Figure 14. Thesis Method

People who would like to follow the approach should have the basic knowledge of data acquisition from different platforms, basic three-dimensional modelling, existing plan drawings of the site and any program that may help them analyse environmental conditions such as thermal comfort and water runoff.

4.1 Developing A Design Approach for Water Management at Street-scale

The main goal of this thesis is to develop a design method that addresses the literature gap in integrating water management treatments to the street-scale. The major challenge for the thesis is to link all the qualitative and quantitative analyses to each other and create a process in which the designers can go back and forth until a suitable solution is designed. Therefore, the approach is intended to be flexible under certain circumstances, and this chapter will explain the steps so that designers can reconfigure them as desired. Mainly, the proposed method aims to guide designers in finding the balance between context and data interpretation. In Figure 14. Development methodology of the approach., how the design approach should be followed and applied is explained in detail. Each step is discussed in further sections.

The approach process is divided roughly into three stages. Firstly, analysing the existing condition from qualitative and quantitative aspects with the data acquired for different purposes such as environmental modelling and 3D modelling. Secondly, the area is divided into patches and generated data is projected onto these patches.

Lastly, selected treatments from the literature review for street-scale are sorted for application based on the patches' projected data.

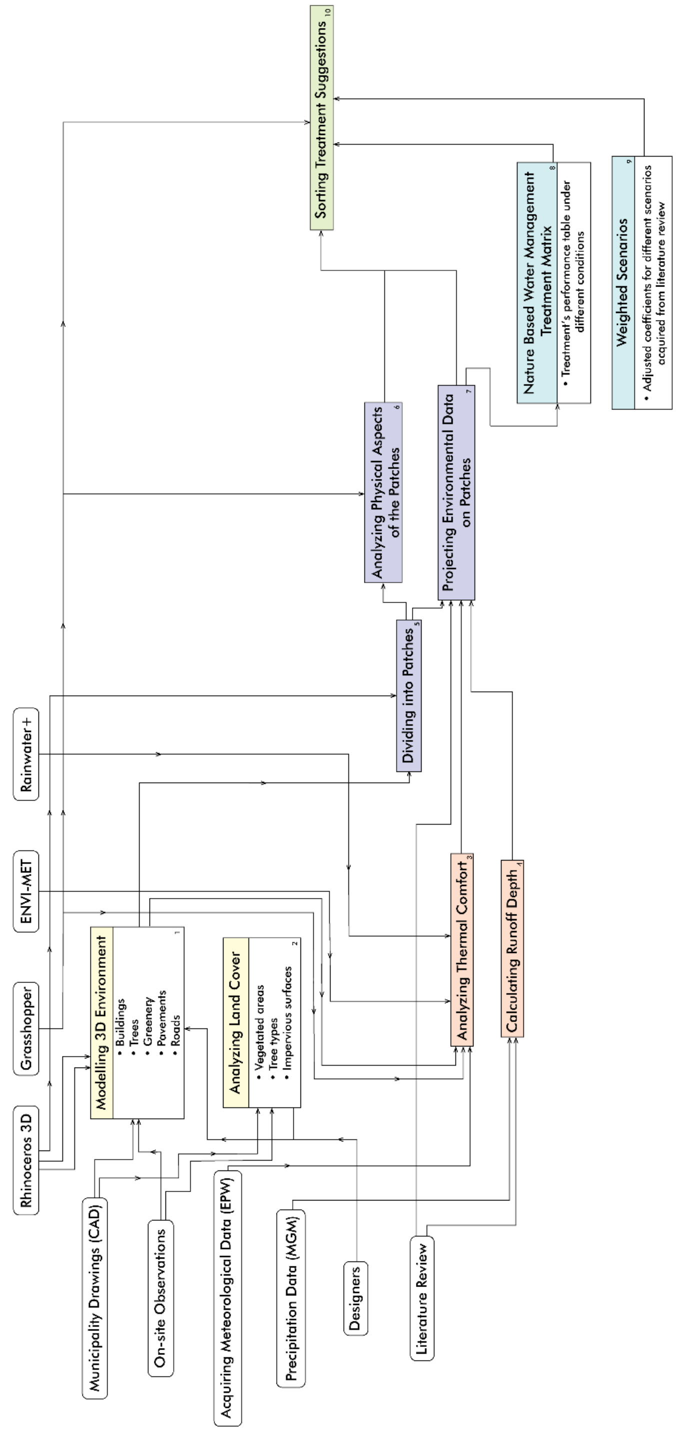

Figure 15. Development methodology of the approach.

In Chapter 4, the development of the approach will be narrated through an abstract city environment with four blocks, a vehicular road and inner pedestrian streets with open spaces parted for different purposes, such as greenery and vehicular parking area, as shown briefly in Figure 15. Four blocks have been chosen to show all different kinds of patching types in the later stages since lesser blocks would not let that and more blocks will just increase the calculation times redundantly. The dimensions of the roads and buildings are taken for default vehicular roads and 4 story buildings which may create enough shade in the area to affect the outdoor comfort calculations.

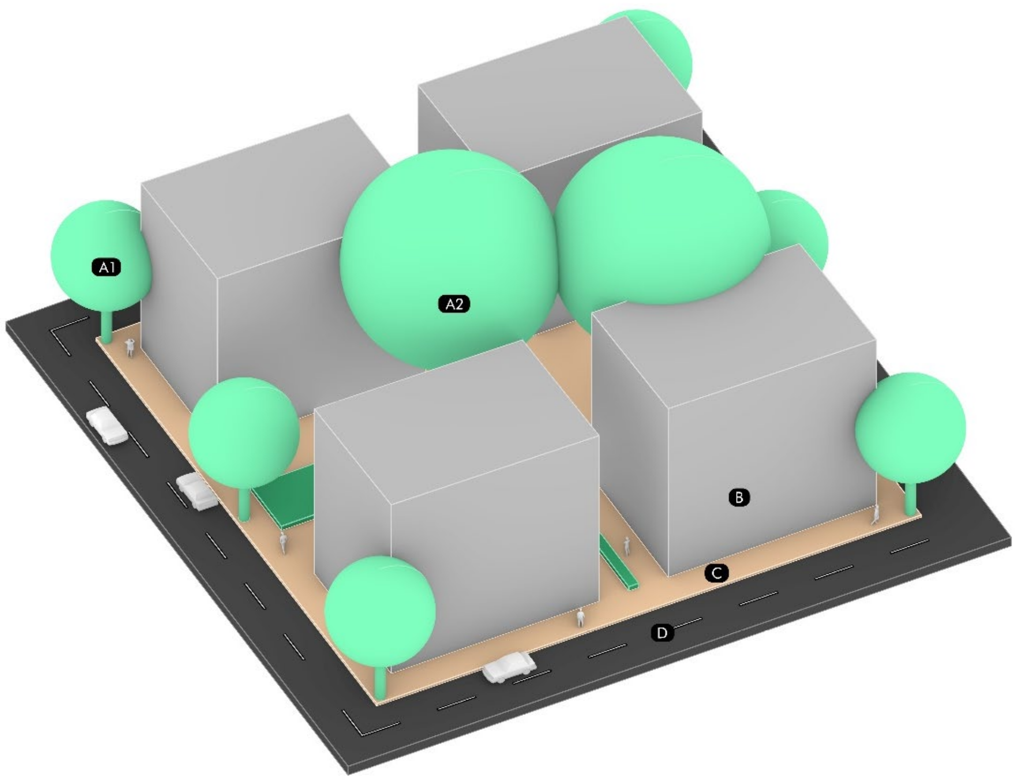

Figure 16. Sample Model. A1) Middle Canopy Tree, A2) Large Canopy Tree, B) Buildings, C) Pavements, D) Vehicular Road.

Figure 17 also indicates the scale of abstraction foreseen for the upcoming case study. In this scale of abstraction, a master plan, which is generated either from the documents retrieved from local municipalities or online mapping tools such as

Google Earth, will be used to create different zones and topography. The site will be detailed in the morphologic assessment phase with sudden and unexpected height differences.

4.2 Gathering Initial Data and Analysing the Existing Condition

The first thing to set up the approach starts with gathering initial qualitative and quantitative data together and making the analysis on different conditions.

4.2.1 Qualitative Analysis of the Site

Developing the approach starts with gathering qualitative data from different sources such as municipality drawings, Google Earth views and site observations. These data are interpreted in the 3D modelling environment Rhinoceros 3D, but any CAD program could have been used to provide the necessary drawings for the later stages. To continue providing quantitative data for creating a comprehensive analysis to design with water, qualitative assessments and observations are compulsory. Therefore, they do not exist in any source, and daily changes can spontaneously happen at a street-scale.

4.2.1.1 Morphological Aspects

In morphologic analysis, the existing physical formation of the study area should be analysed, and the relationship between the street and the buildings should be indicated with the 2D ground plan drawing. In this process, designers acquire essential insights into the daily life, occasional and non-occasional relationships at the site, existing land use, main circulation pattern and the topographical conditions.

The sample model's morphologic assessment in Figure 15 shows the 3D modelling expectations from the approach's scope but also Figure 16 shows the 2D analysis of the master plan generated from Google Earth's view.

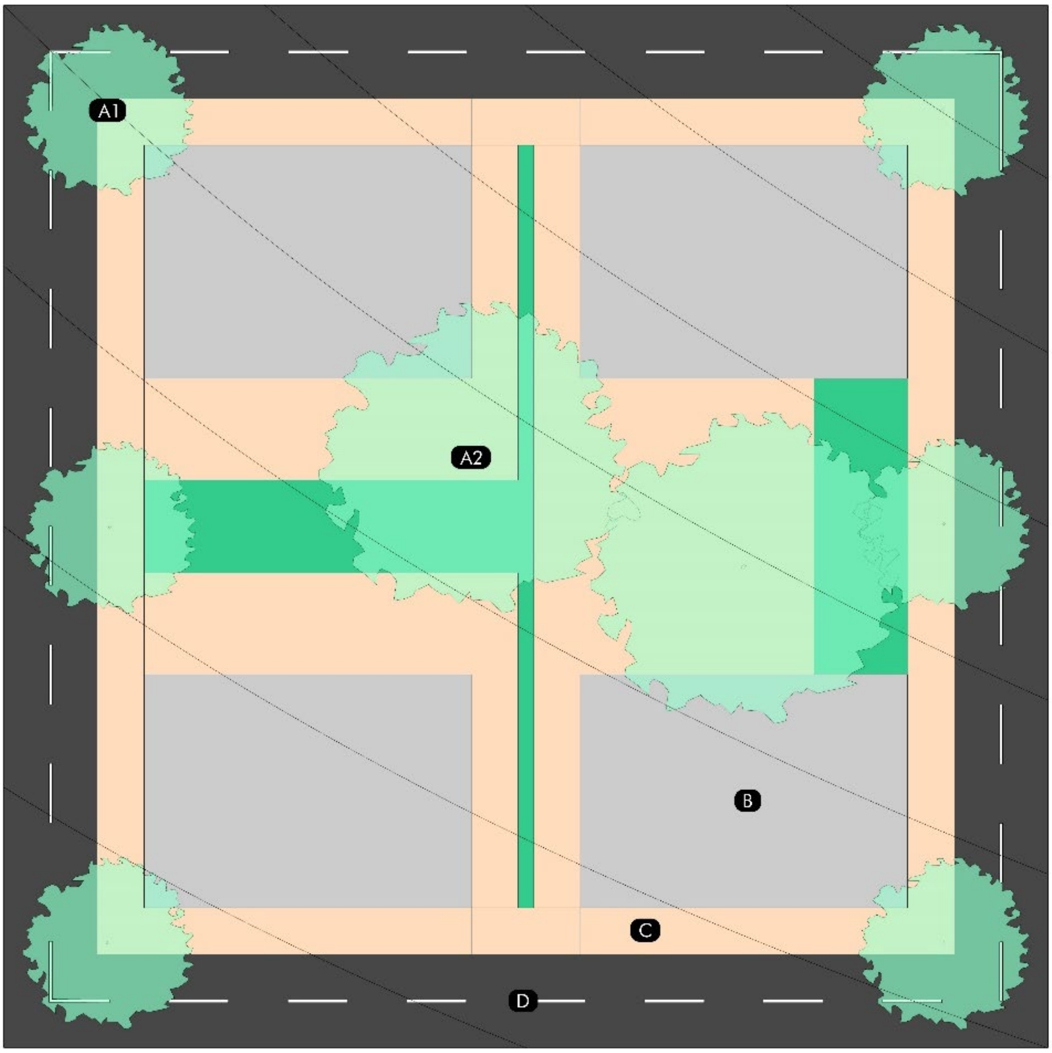

Figure 17. 2D Analysis of sample model.

The generated master plan is used for quantitative analysis, including slope, proximity, and urban patching. Therefore, it is critical to assess the existing situation as accurately as possible and can be supported with on-site observations to prevent unexpected predictions.

4.2.1.2 Land Cover

The land cover analysis is based on the identification of different surface uses. The conducted research indicated that greenery and different impervious surface types drastically affect the performance metrics, including thermal outdoor comfort and runoff amount in the selected area.

Cover descriptions are grouped based on curve numbers from Natural Resources Conservation Services' studies (Cronshey et al., 1985), as indicated in Table 1. Land cover description and curve numbers (Chen et al., 2016).. Based on the table, the land cover analysis aims to determine the existing surface qualities that will be used to analyse the amount of runoff rainwater in the area and calculate outdoor thermal comfort conditions.

Figure 17.demonstrates an example of land cover analysis for the design approach.

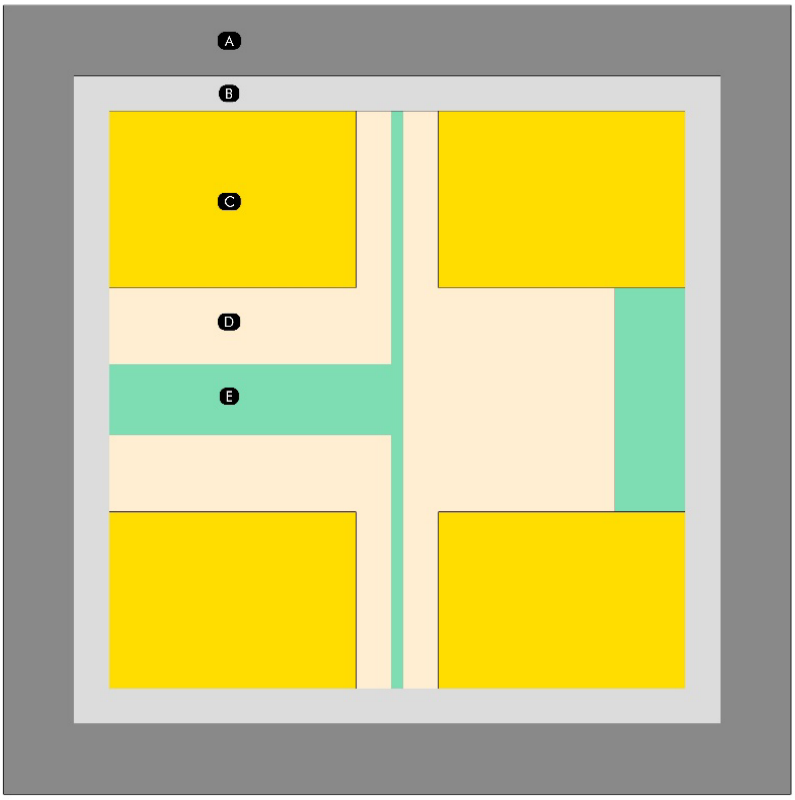

Figure 18 Land cover analysis of demonstrated area. A) Paved Asphalt, B) Gravel, C) Building Footprint, D) Dirt, E) Vegetated Surfaces.

Land cover analysis should be generated from the data gathered from morphologic assessment. It can be supported with additional information from on-site observations, photographs, and other documentation from earlier conditions. When assessing, areas should be included in the closest group.

4.2.2 Quantitative Analysis of the Site

Comparison of the current condition and the effects of interventions is evaluated within a quantitative framework. The quantitative data is fed with interpreted existing qualitative data and the institutions' meteorologic data. Although the sorting algorithm is based on quantitative analysis of the environmental and physical conditions, the application of sorted treatments is based on the designers' comprehensive understanding of the site and context of the day.

4.2.2.1 Environmental Aspects

Environmental analysis helps us understand the analysed conditions' performance based on different indices: runoff amount (m^3) and Universal Thermal Climate Index (UTCI – Degree). Environmental analysis is supported by meteorological data, including but not limited to air temperature, wind speed, humidity, and precipitation amount.

4.2.2.1.1 Runoff Calculation

Runoff amount is an essential indicator of how the water management performs in a selected area and is calculated in volumes. By calculating runoff, designers aim to interfere with the problematic areas and predict future conditions.

Runoff calculation is done before a study conducted at Harvard (Chen et al., 2016) which helps designers to calculate runoff depth in the early phases of design with a tool called Rainwater+ and developed in Grasshopper, which is a graphical programming platform developed by Robert McNeel & Associates to run in Rhinoceros 3D modelling tool. These platforms are widely used and supported with documentation from different sources, so designers who intend to follow the approach being developed by this thesis can be easily used and interpreted. In Rainwater+, the curve number method (Cronshey et al., 1985) is selected for the calculation of runoff depth in this research since it is a widely used for decades. The abstraction scale indicated in the previous chapters reasonably fits this method (Chen et al., 2016)(Chung et al., 2010).

Equation 1. Equation of depth of adequate precipitation (Cronshey et al., 1985).

$$P_e = \frac{(P - I_a)^2}{(P - I_a) + S}$$

P_e = depth of effective precipitation (runoff)

P = total rainfall depth in a storm event

I_a = equivalent depth of initial abstractions

S = maximum possible water retention

According to the study (Cronshey et al., 1985), y on average, I_a = 0.2S; thus, the equation above becomes:

Equation 2. Precipitation constant (Cronshey et al., 1985).

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

The curve number and the maximum feasible retention S are connected.

Equation 3. Maximum possible water retention (Cronshey et al., 1985).

$$S = \frac{1000}{CN} - 10$$

Based on the land cover state of each surface, the curve number is automatically read from the table in the Rainwater computation. For the algorithm to read geometry data from Rhinoceros, detailed land cover conditions must be provided to geometries (individual, group, or layer) in the designer's model.

The developed tool takes the hydrologic soil types' of infiltration rate from United States' Natural Resources Conversation Service's soil group study (Table 3. Hydrologic soil group (nrcs.usda.gov)). It has been applied to the case study.

Table 3. Hydrologic soil group (nrcs.usda.gov)

Type	Infiltration Rate	Texture
A	0.76-1.14 cm/h	Sand and gravels
B	0.38-0.76 cm/h	Coarse to moderately fine
C	0.13-0.38 cm/h	Moderately fine to fine
D	<0.13 cm/h	Clays with high swelling, high water tables

To show an example of runoff analysis, the demonstrated area has been analysed where land covers included asphalt pavement, gravel, dirt and lawn, shows the data being calculated with the Rainwater+ tool.

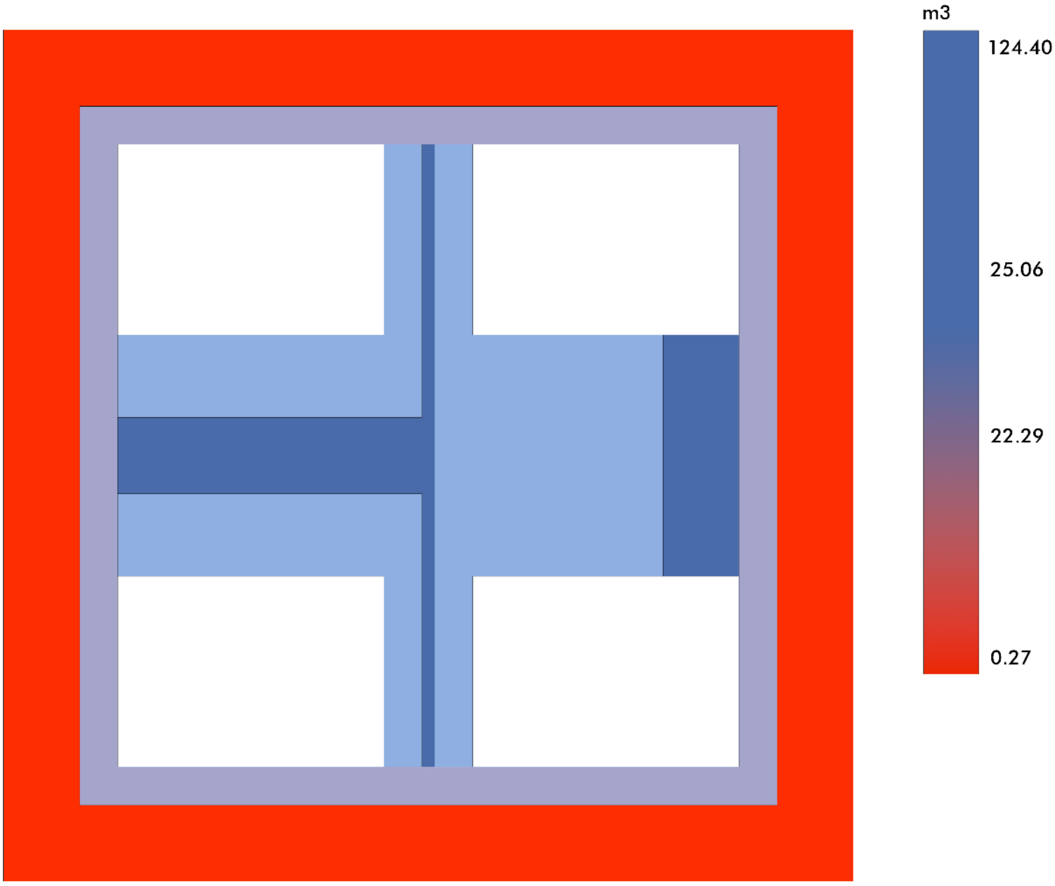

Figure 19. Runoff depth analysis. The bar on the right shows the amount of water running from the surface at m^3 per year.

4.2.2.1.2 Outdoor Thermal Comfort

Increased high albedo surfaces in cities result in higher temperatures which is a phenomenon called Urban Heat Island (UHI). Both natural and artificial variables affect the outdoor thermal climate. The two main natural factors that control the urban thermal climate are local weather and topography. Regarding man-made elements, urbanization is the primary force modifying the urban outdoor thermal environment. Outdoor thermal comfort analysis helps designers understand how people feel in a specific microclimate. There are possible ways of calculating outdoor thermal comforts, such as on-site observations and environmental models. Due to site and equipment restrictions, comfort analysis is done through environmental simulations in this study.

Understanding the modelling capabilities and tool application restrictions about microclimates requires understanding the mean radiant temperature. This is one of the crucial meteorological factors affecting thermal comfort and human energy balance. According to its definition, it is the uniform temperature of a hypothetical enclosure in which radiant heat transfer from a human body is equivalent to radiant heat transfer in the non-uniform enclosure. MRT is one of the indices of calculating the Outdoor Thermal Comfort Index, along with air temperature, humidity and wind speed. Besides air temperature and humidity, wind speed is inclusively calculated during comfort calculations, but unlike the MRT, wind speed calculations have been mostly accurate and widely investigated. Due to different performances of calculating MRT, specific tools have become prominent in outdoor thermal comfort calculations. A study (Naboni et al., 2017) comparing CitySim Pro, ENVI-met V.4, RayMan 1.2, Grasshopper plug-ins Honeybee 0.0.60 and Ladybug 0.0.63, and Autodesk CFD 2016, shows the performances of these tools under different factors.

The temperature of the reference condition that causes the same model response as the actual situation is specified as the UTCI.

The offset, or the departure of UTCI from air temperature, is determined by the actual values of the air and mean radiant temperature (Tr), the wind speed (va), and the humidity, which is measured as either water vapor pressure (pa) or relative humidity (rH) (Bröde et al., 2012).

The following can be expressed mathematically:

Equation 4. UTCI equation.

$$UTCI\,(Ta, Tr, va, pa) = Ta + Offset\,(Ta, Tr, va, pa)$$

Table 4 Variables that are considered by tools in their MRT calculations and distinction of input data (I) and calculated data (C) (Naboni et al., 2017).

	CitySim Pro	ENVI-met	RayMan	Honeybee and Ladybug	Autodesk CFD
Human Body Radiation Exchange					
Shape/Position	Accounted (I)	Simplified (I)	Simplified (I)	Accounted (I)	Simplified (I)
Shortwave absorption	Accounted (I)	Accounted (I)	Accounted (I)	Accounted (I)	Accounted (I)
Longwave emissivity	Accounted (I)	Accounted (I)	Accounted (I)	Accounted (I)	Accounted (I)
Shortwave Radiation Exchange					
Direct radiation	Accounted (C)	Accounted (C)	Simplified (I)	Accounted (C)	Accounted (C)
Diffuse sky radiation	Accounted (C)	Accounted (C)	Simplified (I)	Accounted (C)	Simplified (C)
Diffuse reflected radiation (Buildings)	Accounted (C)	Accounted (C)	Not accounted	Accounted (C)	Not Accounted
Diffuse reflected radiation (Free standing objects)	Accounted (C)	Accounted (C)	Not accounted	Accounted (C)	Not Accounted
Diffuse reflected radiation (Vegetation)	Accounted (C)	Accounted (C)	Not accounted	Simplified (C)	Not Accounted
Diffuse reflected radiation (Ground)	Accounted (C)	Accounted (C)	Accounted (C)	Accounted (C)	Not Accounted
Sky view factor	Deterministically (C)	Deterministically (C)	Fish-eye photo (I)	Ray Tracing (C)	Deterministically (C)
Surface view factor	Deterministically (C)	Deterministically (C)	Fish-eye photo (I)	Ray Tracing (C)	Deterministically (C)
Longwave Radiation Exchange					
Longwave radiation exchange with the sky	Accounted (C)	Accounted (C)	Accounted (C)	Accounted (C)	Not Accounted
Longwave radiation (Buildings)	Accounted (C)	Simplified (C)	Not accounted	Simplified (C)	Simplified (C)
Longwave radiation (Free standing objects)	Not accounted	Simplified (C)	Not accounted	Not accounted	Accounted (C)
Longwave radiation (Vegetation)	Accounted (C)	Accounted (C)	Not accounted	Not accounted	Not accounted
Longwave radiation (Ground)	Accounted (C)	Accounted (C)	Simplified (C)	Simplified (C)	Simplified (C)
(Transpiration (Vegetation)	Accounted (C)	Accounted (C)	Not accounted	Not accounted	Not accounted
Evaporation (Ground)	Accounted (C)	Accounted (C)	Simplified (I)	Not accounted	Not Accounted
Local Wind Speed	Not accounted	Accounted (C)	Not accounted	Not accounted	Accounted (C)
Local Wind Direction	Not accounted	Accounted (C)	Not accounted	Not accounted	Accounted (C)
Sky view factor	Deterministically (C)	Deterministically (C)	Fish-eye photo (I)	Ray Tracing (C)	Deterministically (C)
Surface view factor	Deterministically (C)	Deterministically (C)	Fish-eye photo (I)	Ray Tracing (C)	Deterministically (C)

Among all the tools, ENVI-MET steps up with accounting for local wind and direction, detailed vegetation inclusion and accounting for various ground types.

Table 5 Context of applicability of the tools (Naboni et al., 2017).

	CitySim Pro	ENVI-met	RayMan	HoneyBee & Ladybug	Autodesk CFD
Context with various ground types	Yes	Yes	No	No	No
Fields with simple buildings	Yes	Yes	Yes	Yes	Yes
Fields with geometrically complex buildings	Yes	Partially	No	Yes	Yes
Fields with free-standing objects (canopies and curtains)	Partially	Partially	No	Partially	Yes
Calm places (airflow)	Yes	Yes	Yes	Yes	Yes
Windy places	No	Yes	No	No	Yes
Contexts with trees and green entities	Yes	Yes	Partially	No	No

Based on the study, ENVI-MET has been chosen to use in this study since urban environments at street-scales with suggested interventions with trees, vegetation and surface variations will require their differences to be accounted detailed in the model.

ENVI-MET requires air temperature, humidity, and wind speed to be given initially. Therefore, these inputs have been selected from Energy Plus's weather data archive (https://energyplus.net/weather).

For the material appointment, from the library of ENVI-MET, the most similar ones to land cover analysis have been used for the model. The analysis of the sample model is shown in Figure 19. UTCI analysis demonstrated.

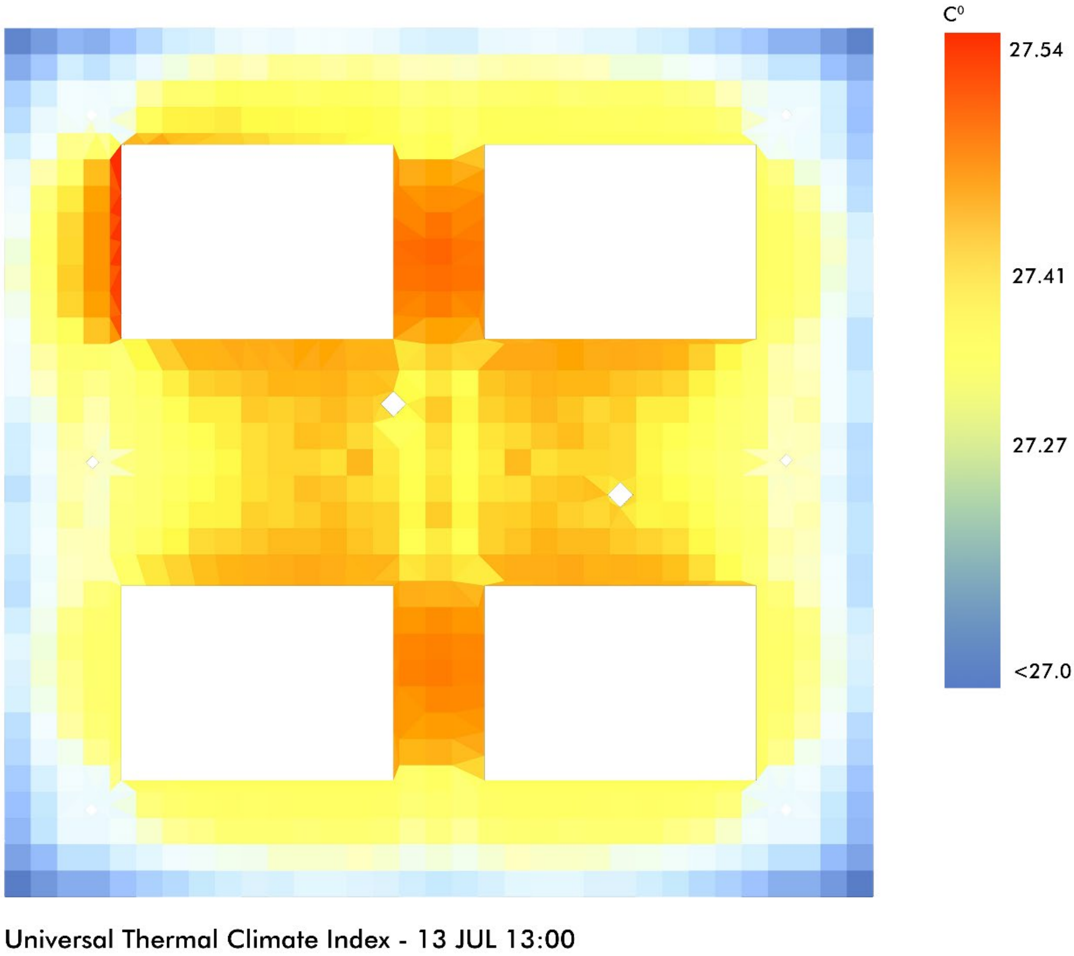

Figure 20. UTCI analysis demonstrated.

Due to heavy computational load and calculation time in ENVI-MET, the model has been set for only an hour on a specific day. The 13th of July is selected as it resembles the typical summer.

Calculation resolution in that example is 1x1 meter, meaning the given surface is divided into 1x1 meter squares, and data represent that area. Smaller calculation dimensions would mean better resolutions and more accurate predictions while increasing the calculation time drastically.

4.2.3 Physical Aspects

Physical properties of the site affect how the water moves at the site. Therefore, understanding the physical condition and acting according to that is crucial in water management. A physical analysis is done prior to the urban patching since the patched surfaces' conditions are physically affected, contrary to environmental analysis.

4.2.3.1 Slope Analysis

The slope ratio affects how fast the water runs through the surface. Therefore, it affects how much the surfaces will have the water to filtrate to the soil below. According to the slope ratio, faster water filtrating treatments should be favoured to prevent increased runoff, especially during excessive rains causing floods.

4.2.3.2 Proximity Analysis

Distance to the nearby buildings affects the type of treatment since water running down from the gutter is a valuable source and method which can absorb that water should be favoured when selection is made. On the other hand, trees cannot be planted when their roots are close to buildings. Other than that, most treatments are independent of the buildings' proximity.

4.3 Determination of the Patches

Tracking the similarities and deducting rules from the consecutive decisions may help to simplify the problem up to a point. From these points, this thesis focuses on developing urban patching based on the existing built environment's footprints and outdoor spaces' relationship. The patches create a basis for the designers to follow to synthesize their initial ideas with the built environment and contribute to it with an integrated water management system while improving outdoor comfort space quality with greenery for habitants. Patches are used as referencing for the built environment.

Figure 21. Urban Patching Example demonstrates the main patching areas, defined mainly by the building footprints and accessibility elements such as pavements. Buildings refer to the physical constructs that majorly delimit the outdoor spaces. Accessibility elements are minor elements which, although physically may not lead people all the time, define the characteristics of the area by prioritising one type of user, such as vehicles, pedestrians, house owners etc. Moreover, sudden height differences may behave as outdoor space definers; in such cases, these elements should be included in the patching. Since the surrounding of the building is predefined in most urban plans, the orientation of the building is defined by the entrance side and pedestrian way passing by the street.

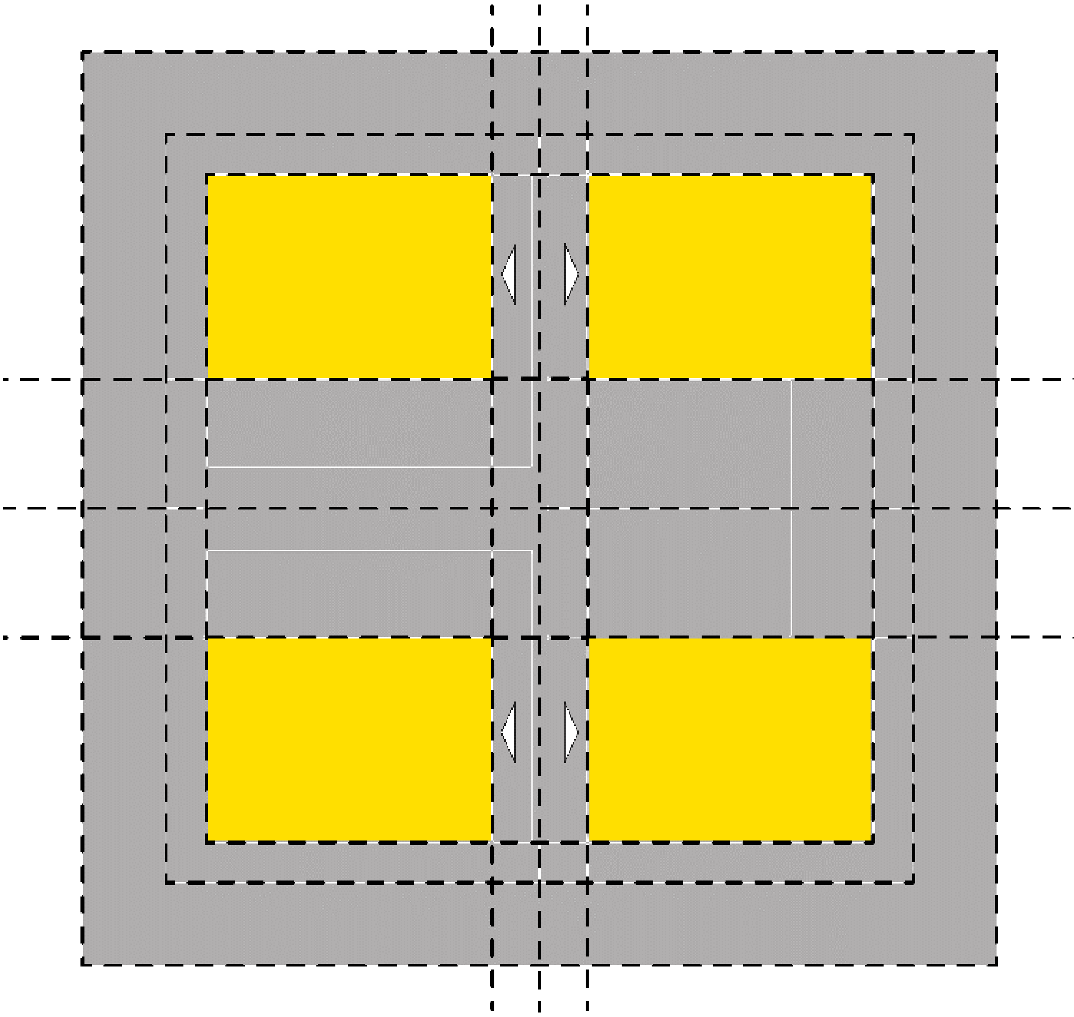

Figure 21. Urban Patch Reference Lines

The reference lines divide the area into six, but not necessarily, parts that may define most of the urban places. These types are vehicular road, front of the building, in-between the buildings, back of the building, in-between of the backs and in-between of the fronts. Although the characteristics of the patch type may differ based on the context, the division still refers to the planning scheme of the area and may be interpreted.

Figure 21. Urban Patching Example shows the patching on the sample model. As stated in the previous paragraph, according to the entrance, the orientation of the building is determined, and the back and sides of the buildings are defined. This

patching method will be a fundamental understanding of interpreting the urban environment to configure a water-friendly environment.

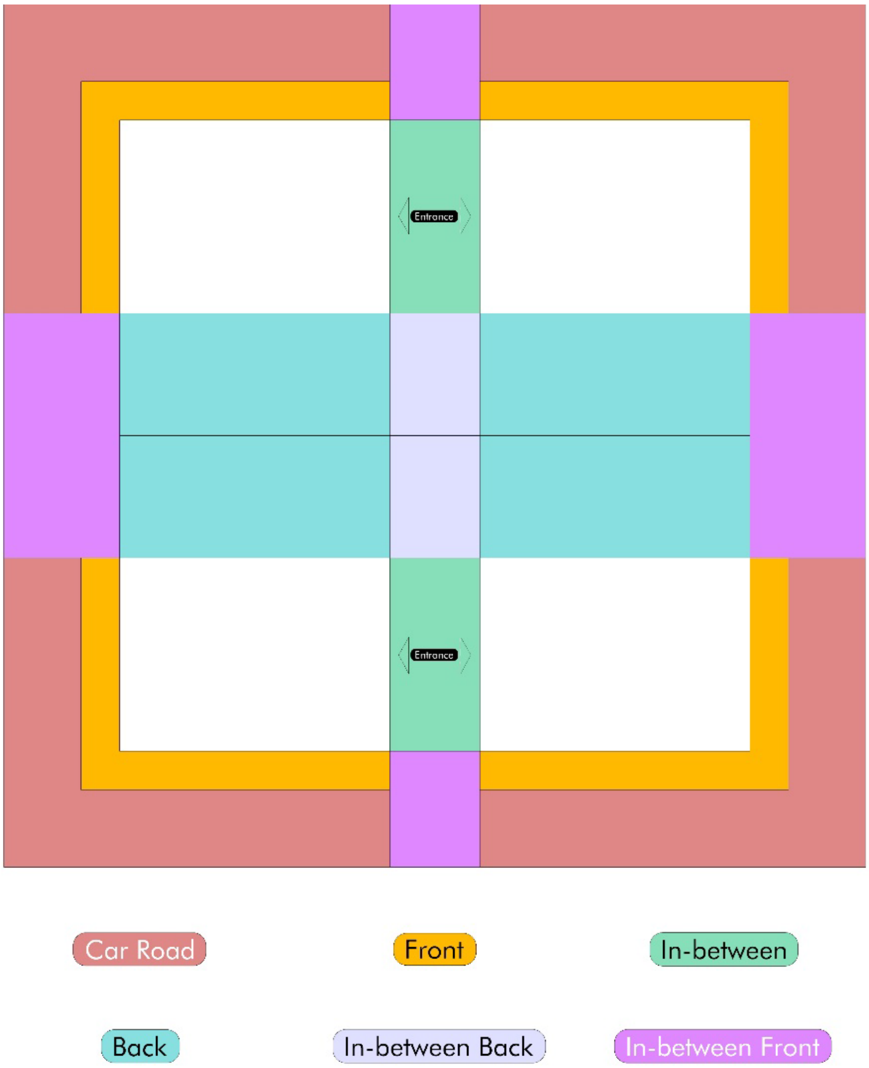

Figure 22. Urban Patching Example

4.3.1 Physical Analysis of Patches

After the patches are defined, the physical analysis can proceed accordingly, as mentioned in Chapter 4.2.2.

In physical analysis, properties of each patch are analysed and projected contrary to environmental analysis, where the diagnosed condition is projected onto the patches.

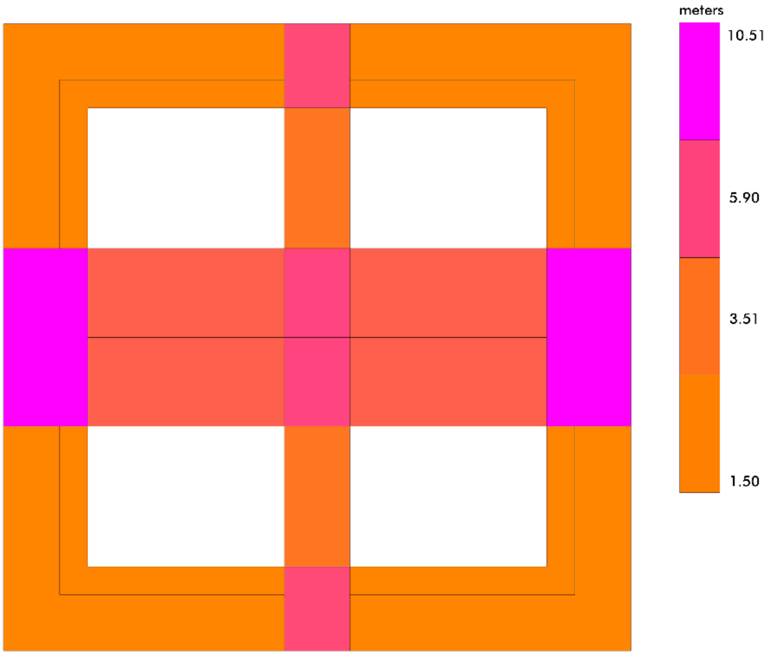

Figure 23. Proximity Analysis

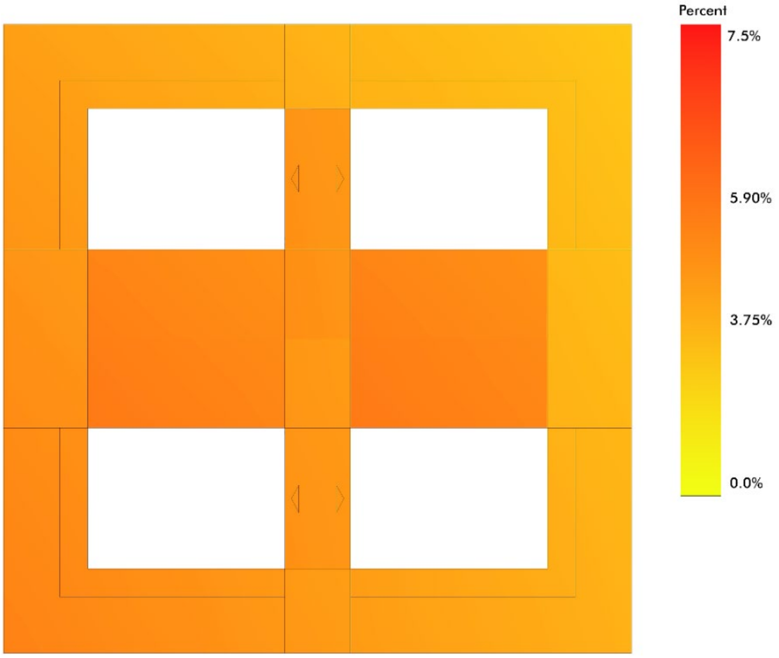

Figure 24. Slope Analysis

4.3.2 Projecting the Environmental Analysis onto Patches

To test the patches' fitness in the previously mentioned categories, acquired data from environmental simulations are projected onto the surfaces.

Since the UTCI is calculated in 1x1 meter of the grid, taking the average of the squares data that stays in the patch gives us the overall thermal comfort performance.

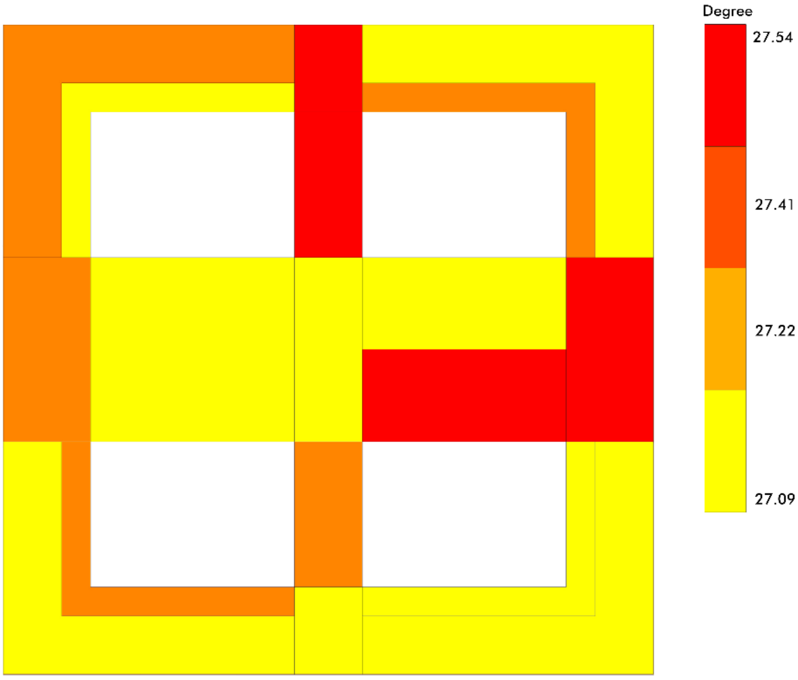

Figure 25. UTCI values projected onto the patches

Calculating runoff depth for the patches is like thermal comfort. Areas which are inside the patch are calculated based on their runoff depth.

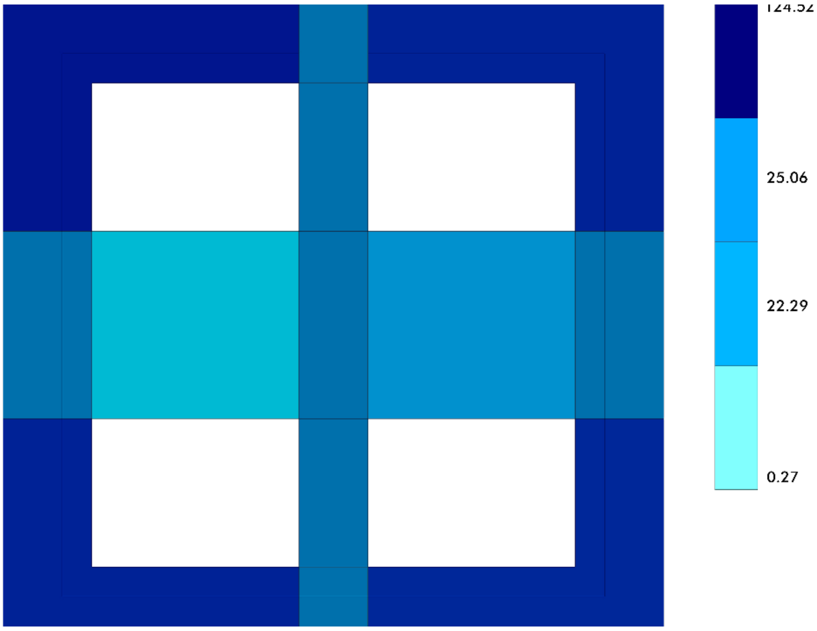

Figure 26. Runoff volume projected onto the patches

4.4 Nature Based Water Management Matrix

To create a approach for designers to follow and apply the treatments in the light of qualitative and quantitative data, a matrix is composed of the insights from the literature view explained earlier in Chapters 2 and 3. This matrix classifies the treatments based on the conditions analysed before: outdoor thermal comfort, runoff depth, slope, and proximity analysis.

Figure 26. Treatment Matrix demonstrates the matrix upon which the treatments will be sorted. Designers may also investigate the matrix to diminish their design thinking during or before the application.

Values define the effectiveness of the treatments under different conditions. Since the absolute performance of the application cannot be determined before considering many parameters as indicated in the earlier chapters and measuring after application, the values are shallowly indicating the effectiveness and aim for giving an initial idea and sorting for designers. Because of that, secondary and thirdly tunings are considered for designers to follow, which are scenario-based treatments and designers' interpretation flexibility on the patch.

	Pervious Surface	Street Tree	Rain Garden	Bioswale	Vegetated Buffers	Data Type	
Affected by the design approach	++	-	+	+	+	Discomfort Cold	UTCI Analysis
	0	0	0	0	0	Comfort	
	-	++	+	+	+	Discomfort Hot	
	+	++	+	+	+	Runoff<1000	Runoff Analysis
	+	+	+	++	+	R 1000-3000	
	+	+	++	+	+	Runoff>3000	
Not affected by the design approach	0	0	+	+	+	Slope 0-15	Slope Analysis
	+	0	+	++	+	Slope 15-30	
	+	0	+	++	++	Slope 30>	
	0	-	+	0	0	Distance<2	Proximity Analysis
	0	0	0	0	0	Distance>2	

++ Major contribution, + Minor contribution, 0 Hardly different, - Worse than before

Figure 27. Treatment Matrix

4.5 Scenario Based Treatment Co-efficient

As the approach aims for a wide range of application areas, different areas may require additional water management scenarios at their macro scales. A specific range of flexibility is necessary for the more efficient application of treatments. Although cities develop water management goals for macro scales, micro-scale adaptations become necessary. In this study, specific qualifications are explained and weighted in the system rather than specific scenarios for the designer. In that sense, three different types of priority are chosen, and the weighting of the treatments within these systems are explained.

Pervious Surface	Street Tree	Rain Garden	Bioswale	Vegetated Buffers	
Prioritized	-	-	-	Prioritized	Filtration
-	Prioritized	Prioritized	-	Prioritized	Detention
-	-	Prioritized	Prioritized	-	Infiltration

Figure 28 Weight distribution for different purposes

4.5.1 Filtration

Water touching the earth becomes increasingly contaminated as it stays on it. In the areas where the runoff amount is high, running water should have been filtrated before infiltrating to earth. Therefore, when the site has high runoff amounts, favouring treatments with better filtration qualities (Tunçay, 2021). Permeable surfaces and vegetated buffers are effective at filtration majorly compared to other techniques and should be prioritised.

4.5.2 Detention

When the amount of water falling on the ground is large, water accumulates and sweeps in large quantities, affecting human lives or losing rich soil. To prevent that, water should be slowed down with treatment methods. Moreover, water will be redirected to other retention areas that can be filtered and slowly infiltrated. Raingardens, vegetated buffers, and trees slow the water down and help the water slowly infiltrate the ground (Tunçay, 2021).

4.5.3 Infiltration

Water infiltrating under the ground helps feed underground waters and is filtrated through the soil's layers. Moreover, infiltrating water is evapotranspiration, so it helps improve the water cycle and restore underground waters. Bioswales and rain gardens are highly efficient and should be prioritised.

4.6 Sorting Treatment Suggestions per Patch

When the calculations and scenario selection are decided, all patches are matched and evaluated with the help of the design matrix (Figure 26. Treatment Matrix). Treatments are sorted according to the highest values by simply assigning values to the patches.

In the sample model, when the scenario is selected to fine itself for infiltration,

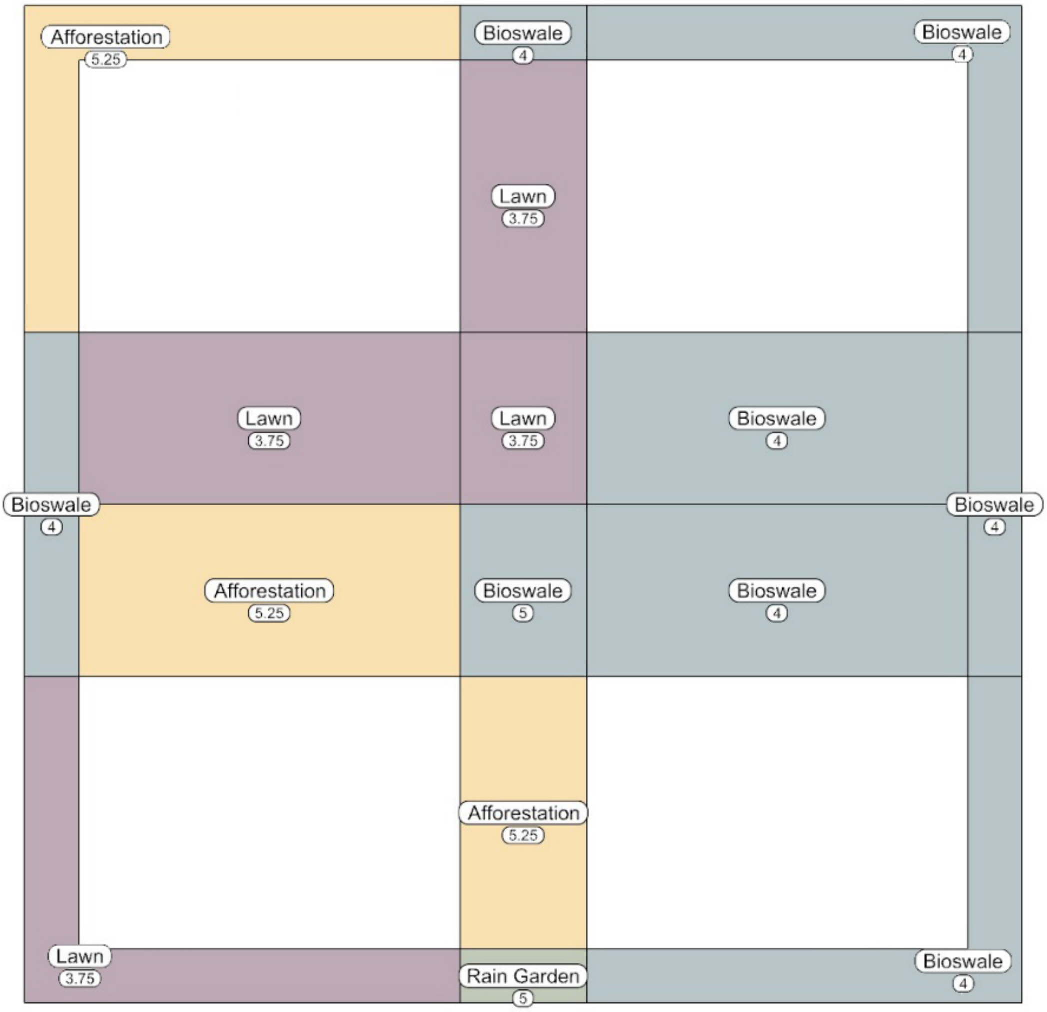

Figure 29. Sorted Treatments and Values

4.7 Further Stages of Decision and Application of Treatments

The approach aims to sort the treatments depending on the decided environmental conditions. Designers using the framework proceed by either selecting the proposed treatments or developing their approaches with additional context analysis they prefer. In the end, the approach aims not to limit the designers but guiding them. Therefore, unique approaches for different sites should be developed and integrated into the application and detailed design processes.

Possibilities of what can be done at further stages of using approach is demonstrated at case study which is explained at Chapter 5.

4.8 Limitations During the Development of the Approach

Several limitations while developing the approach, have been ignored and not included in the process. The limitations are explained below:

- Soil type is an essential parameter while calculating runoff depth and choosing treatments. Nevertheless, for the cities already being developed or rapidly and poorly developed, soil type is rather hard to acquire or measure at the site. Therefore, soil type is not included as a parameter in the design matrix.
- NBS tools that are at building scale are very effective for water management and thermal comfort improvement. However, the poor connection between patch and vertical treatments made using vertical treatments unnecessary and arbitrary. Regardless of the surface application, vertical greeneries and green roofs can be integrated into the existing built infrastructure if available.
- Scenario narration is relatively more minor than what the nature-based solutions are capable of. Scenarios are created depending on the treatments that are selected. Therefore, having more treatments in the process would increase the scenario pool.
- Urban scenarios with street-scale architectural interventions are excluded as input parameters. Nevertheless, designers may include that parameter in the further stages of the approach where the application and context analysis is discussed.

The stated limitations can be reconsidered in a study with more extensive and detailed scopes.

CHAPTER 5

CASE STUDY

The presented approach for integrating nature-based water management treatments to urban context is demonstrated on a case study for application for a building island in Ankara. The main purpose of the case study is to show the use and correct interpretation of approachs in a real scenario. Moreover, the author aims for this study to be influential work for the decision-makers and designers to follow, evaluate and implement in their built environments. Ankara, with everchanging morphological and land cover patterns, is selected as a study area. For the time limitations of the study, a small portion of the urban fabric is chosen to be investigated and designed. However, the process is applicable for more extensive investigations and designs.

5.1 Site Selection

For the appropriate implementation of the approach, a good mixture and variety of outdoor spaces are selected in Ankara. Around Atatürk Boulevard in the Çankaya district, crowded area in Ankara, including well-known streets like Tunalı Hilmi, Esat, Tunus and J.F. Kennedy (Figure 29. Central streets of Ankara and study area view from Google Earth.).

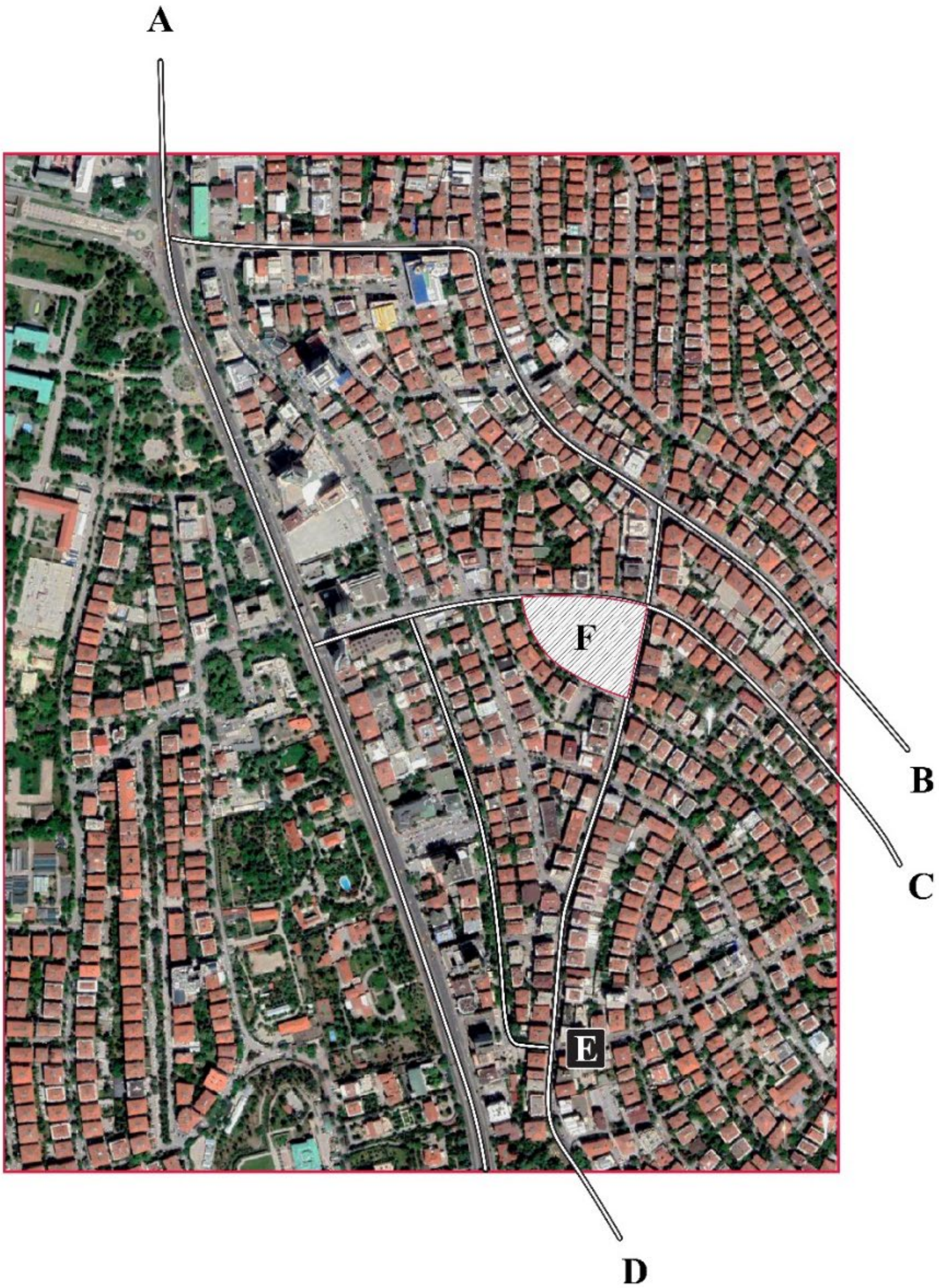

Figure 30. Central streets of Ankara and study area view from Google Earth.

A) Atatürk Blvd. B) Esat St. C) J.F.Kennedy St. D) Tunalı Hilmi St. E) Tunus St.
F) Study Area

At the heart of this area, surrounded with J.F. Kennedy, Tunalı Hilmi and Büklüm streets, a building island with sixteen buildings is selected to be studied. This area is shown in Figure 30. Study area view from Google Earth.

Figure 31. Study area view from Google Earth.

A) Büklüm St. B) Tunalı Hilmi St. C) J.F.Kennedy St.

Study area is selected for reasons explained below:

- Site is well-defined with major streets.
- Site is surrounded by dynamic places and situated at the centre of the urban life.
- Site has considerable elevation differences which area expected to affect the outputs. The sudden height difference crossing through the backyards is

especially an exemplary input which should be considered in other sites carefully (Figure 31. Sudden height difference at the site..

- Outdoor space use and land cover have variety which can affect the process of developing the treatments.
- The existing green areas at the site challenges designers to integrate the new treatments accordingly.

Figure 32. Sudden height difference at the site.

5.2 Intervention Steps

Processes explained in the Chapter 4 for design approach development is applied to the case study (Figure 14. Development methodology of the approach.). First the site is investigated qualitatively and quantitatively. During these investigations, different methods such as on-site observations, photographing, and drawing existing situation from satellite image are used. Additional site-specific analysis has been conducted and explained in detail to guide similar cases.

5.2.1 Qualitative Analysis

First impression of the site is acquired via satellite images taken from Google Earth (Figure 32. Study area satellite image (Google Earth).).

Figure 33. Study area satellite image (Google Earth).

2D Model

From these images, the location of the buildings and footprints, vehicular roads, green areas and secondary hard surfaces such as gravel is modelled in 2D with

Rhinoceros 3D (Figure 32. Study area satellite image (Google Earth).)(3D Modelling program).

In the site plan, temporary buildings such as taxi stop (Figure 33. Taxi stop (Google Maps).), slum houses (Figure 35. Slum house at the back of the buildings.) and illegally built structures such as closed parking lot (Figure 36. Illegally built closed parking garage.) and informally extended closed area of a hotel (Figure 34. Illegally extended closed area of a hotel (Google Maps).) are excluded in the drawings in order to stick with the legal and long-term urban plan of the site.

Figure 34. Taxi stop (Google Maps).

Figure 35. Illegally extended closed area of a hotel (Google Maps).

Figure 36. Slum house at the back of the buildings.

Figure 37. Illegally built closed parking garage.

In the light of these observations and existing 2D CAD plan, the site is remodelled as seen in Figure 37. Study area in 2D.

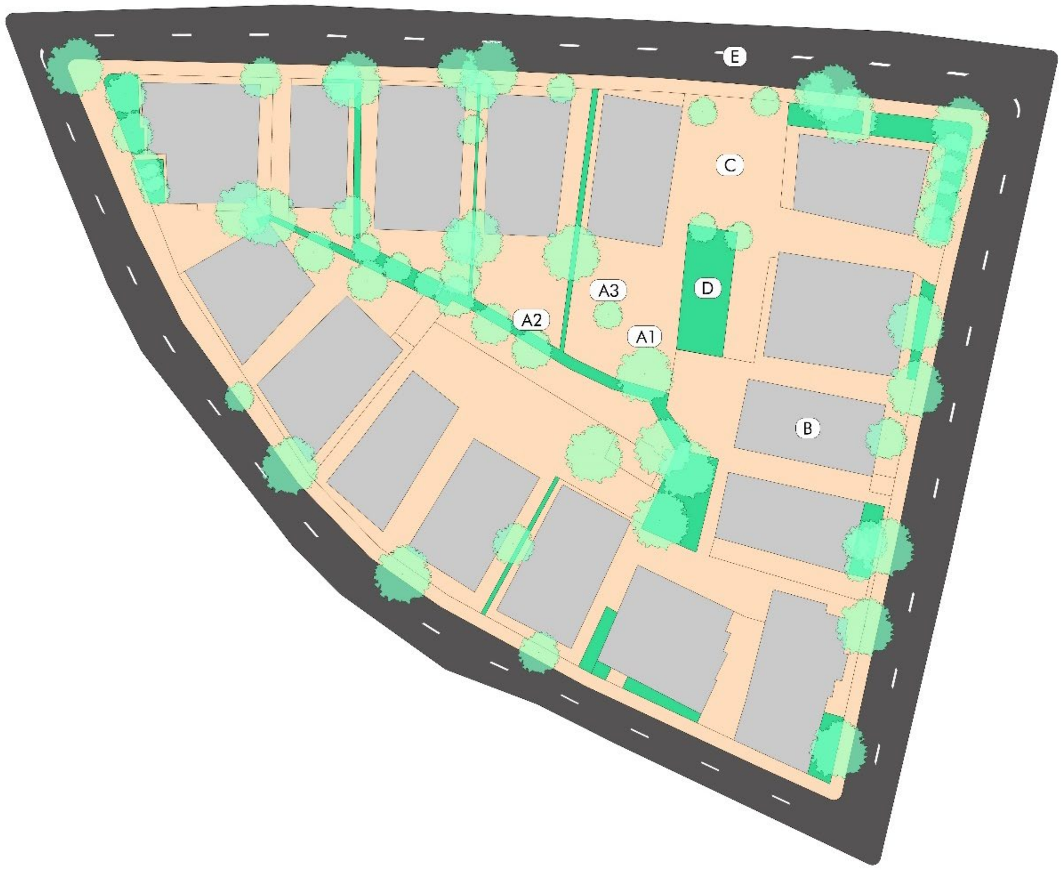

Figure 38. Study area in 2D.

A1) Middle Canopy Tree, A2) Large Canopy Tree, B) Buildings, C) Pavements, D) Greenery, E) Vehicular Road

3D Model

Since the information acquired from satellite image is insufficient, additional tools are used to show the ground coverage, relationship between the buildings and topography and use of places, a series of photographs taken from an on-site observation is used a detailed 3D model of the area which will be used for simulations and analysis afterwards. The 2D model is three-dimensioned in Rhinoceros 3D.

The existing topography of the site is generated via CAD Mapper (https://cadmapper.com). CAP Mapper is a tool that can be accessed via web browsers and create 3D topography of the site using Google Earth's database. The given topography (Figure 38. Input Topography.) does not include the buildings footprints or landscape. It is an approximated topography model that is generated via depth map from satellites. Therefore, the topography is used as a reference together with the site observations and drawings of the existing plan. Height contours are considered as height references and integrated to existing pattern.

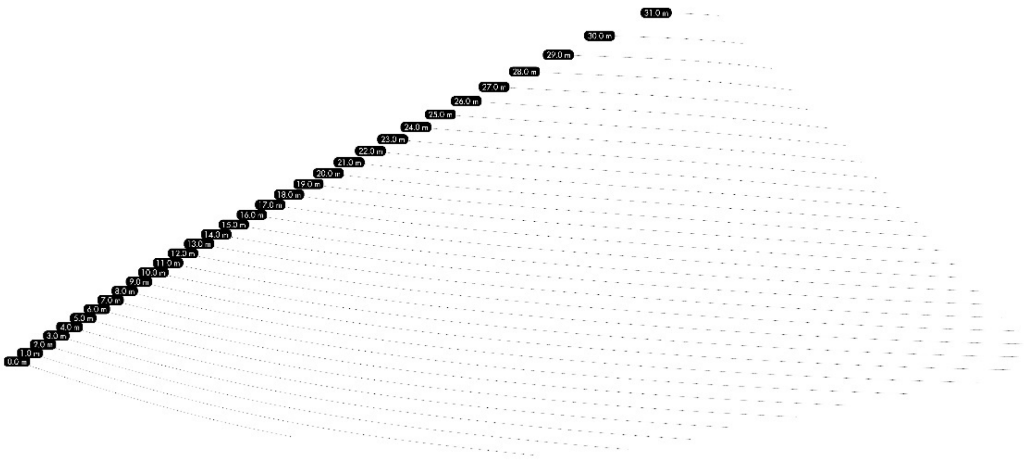

Figure 39. Input Topography.

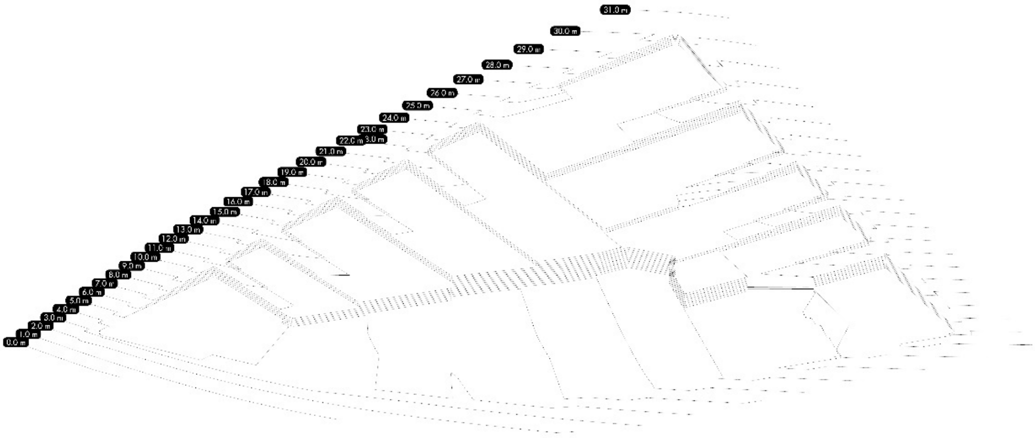

Figure 40. Modelled topography with the site elements.

During 3D modelling phase, site photographs and on-site observations are used as an assistant tool. The height of the buildings is approximated based on floor counts. One floor is taken as 3.5 meters height and all the buildings are extruded according to that height and their floor numbers. Since the roofing is not an input for runoff depth, proximity and slope calculations were not included in the model and therefore in calculations. In normal standards where the high-resolution UTCI values are needed, roofing may affect the results. However, in this case, the grid-based calculation scale is too small, so it would not make a difference in the UTCI calculations.

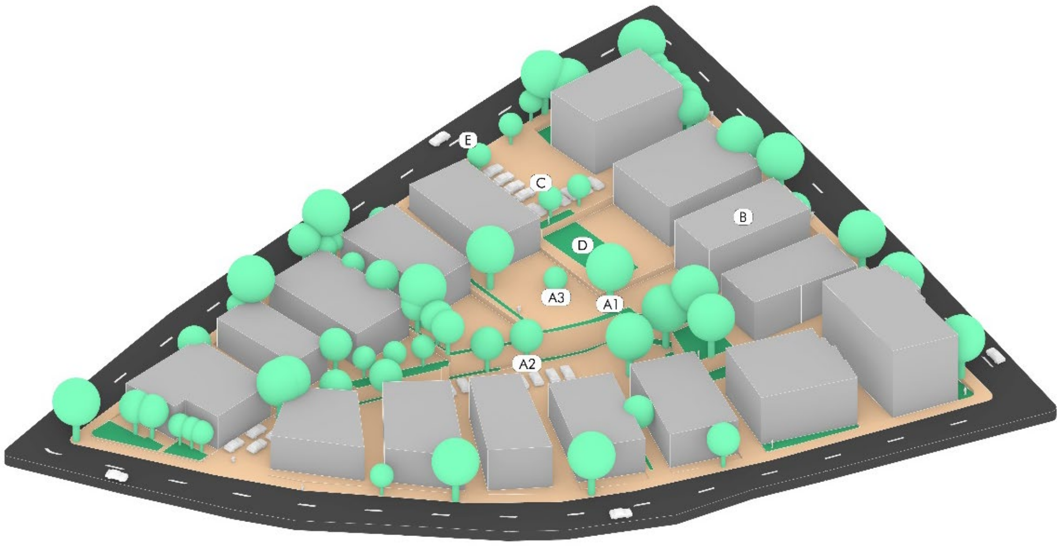

Figure 41. Study Area in 3D.

A1) Middle Canopy Tree, A2) Large Canopy Tree, B) Buildings, C) Pavements, D) Greenery, E) Vehicular Road

Land Cover

Green elements at the site are abstracted into certain types. Trees are divided into different categories based on their canopy width large (15 meters), medium (10 meters) and small (5 meters). All the canopy types are considered as round as it may be seen in the model. Green surfaces are considered as one type of medium-dense grass. For the green surface consideration, the main aim is to take the surface as a growing medium for grass and types. In that sense, plant decision is another limitation that is part of the study and not included to extend the topic larger than it aims for. For future studies, plant types could be a parameter for developing such a system for cities.

Hard surfaces are divided into two parts. Firstly, asphalt surfaces are primarily used by vehicles. Although these surfaces extend in-between the buildings and behind the buildings as vehicular parking areas, the type of asphalt and its integrity is different as from Figure 41. Land cover analysis.. Therefore, main roads are considered as asphalt surfaces and secondary roads and other hard surfaces are considered as gravel. For similar challenges to roof modelling, the different types of soils are not included in the model since it was going to create a complicated model to understand and interpret. In previous studies with better calculation resolutions, different types of hard surfaces can be modelled and integrated to the simulation model.

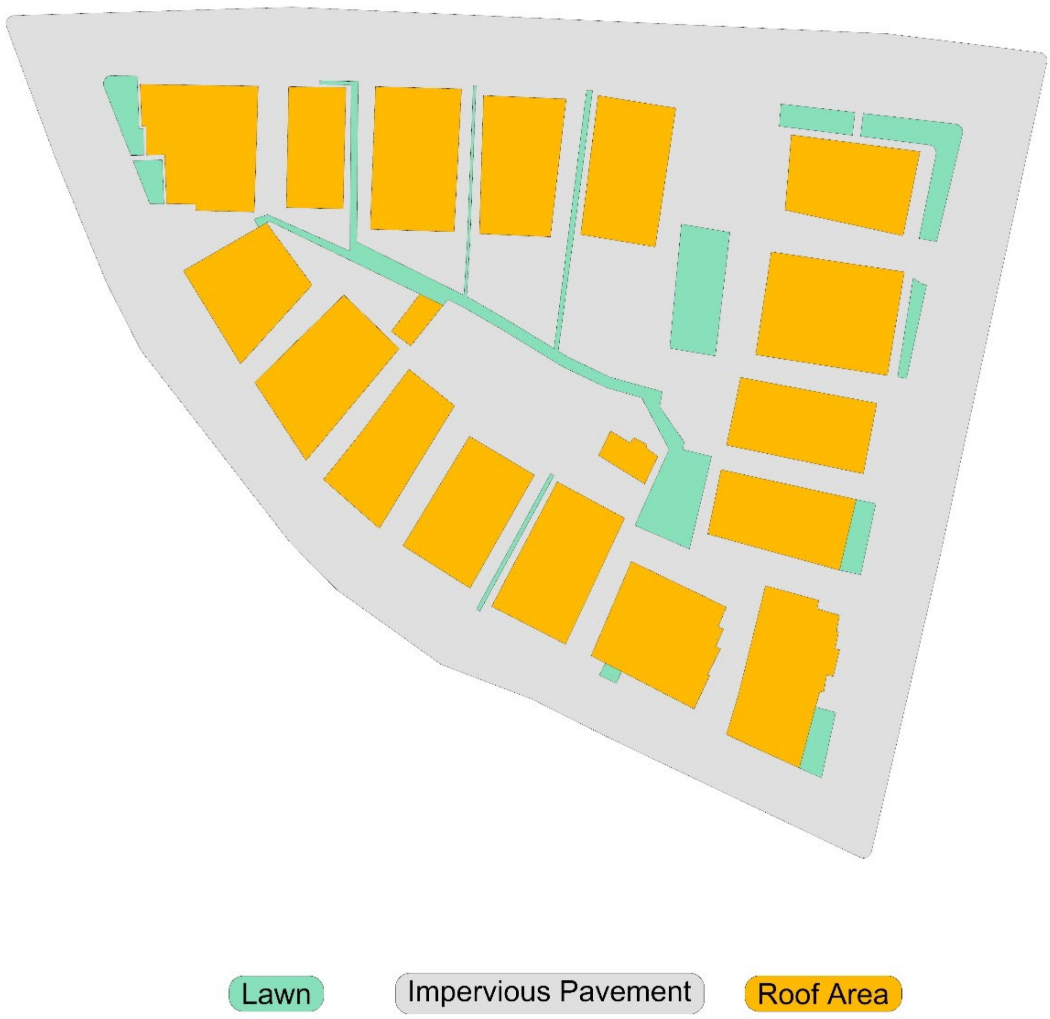

Figure 42. Land cover analysis.

Program Analysis

Since the area is in the densely built and programmatically complex and ever-changing part of the city, program analysis is done for an in-depth analysis of the site

The site includes different programs such as municipality buildings, hotels, banks, an abandoned night club, different type of stores and restaurants and residential buildings (Figure 41. Land cover analysis.. Most of the buildings are residential units with different programs at the ground level. The mixed-use of the area shows a dense human movement in the area. The spaces which can habitat people who pass through or stay in the area would be beneficial for the urban well-being. Private zones are the territories which is belong the owners of the land and not open to public.

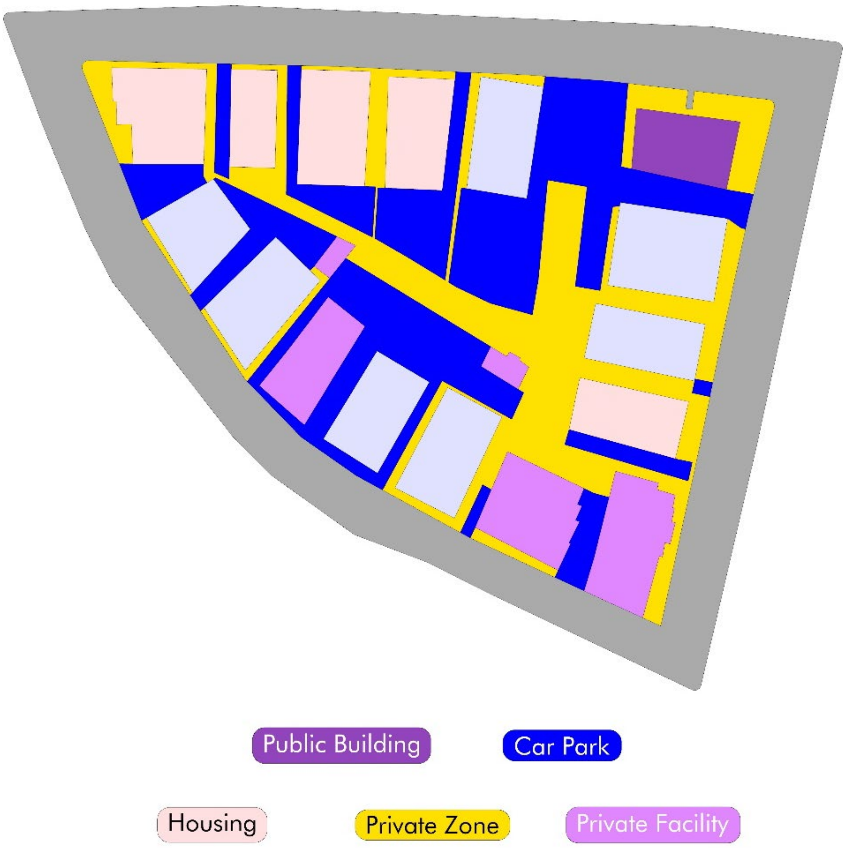

Figure 43. Program analysis of the site

5.2.2 Environmental Analysis

Abstracted 3D environment of the site is used for environmental simulations. Two different analysis is done for the site which are mentioned in Chapter 4 as outdoor thermal comfort and total runoff depth.

Outdoor Thermal Comfort

As mentioned before (4.2.2.1.2), an index called UTCI (Universal Thermal Climate Index) is used for outdoor thermal comfort analysis. For the calculations, Lite version of ENVI-MET program is used. ENVIMET demands the initial air temperature, relative humidity and wind speed for the calculation bound. Therefore, this data is fed with EPW file (https://www.ladybug.tools/epwmap/). EPW file contains recorded meteorological data at specific points. For Ankara, several EPW files are available. Among these EPW files, a post which as at Etimesgut is selected.

Due to licencing limitations, only 50x50x050 meters of area could have been calculated leading to the nine meters of grid dimensions for the calculation. Moreover, lite version does not allow users to use the full potential of the processors and therefore limits the calculation time. Therefore, for the sake of completion of the study in the limited given time, one specific day and a twelve hours of time range are selected. Within these limitations, the medium hot day of the year is taken and calculated from 9am to 9pm.

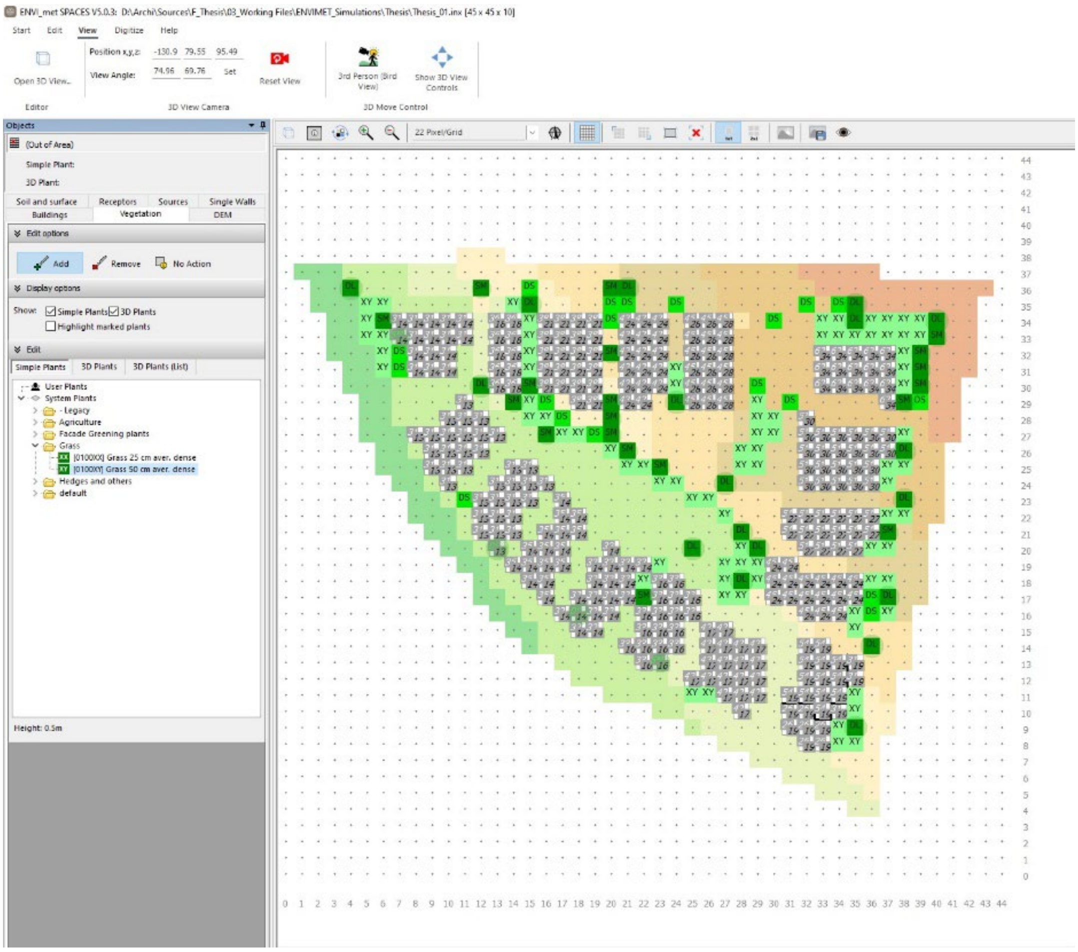

Figure 44. A screenshot of the model in ENVIMET's interface. It shows how the site elements are interpreted in ENVIMET.

The results shown in Figure 44. UTCI analysis at 9am., Figure 45. UTCI analysis at 1pm., Figure 46. UTCI analysis at 5pm.,and Figure 47. UTCI analysis at 9pm. show how the building morphology of the site affects the outdoor thermal comfort around the buildings. Based on this analysis, it can be inferenced that thermally discomfort areas should be treated mainly with shadow creating elements.

The analysis is done at 13th of July as it is the typical hot summer day of the year for Ankara. The typical hot summer

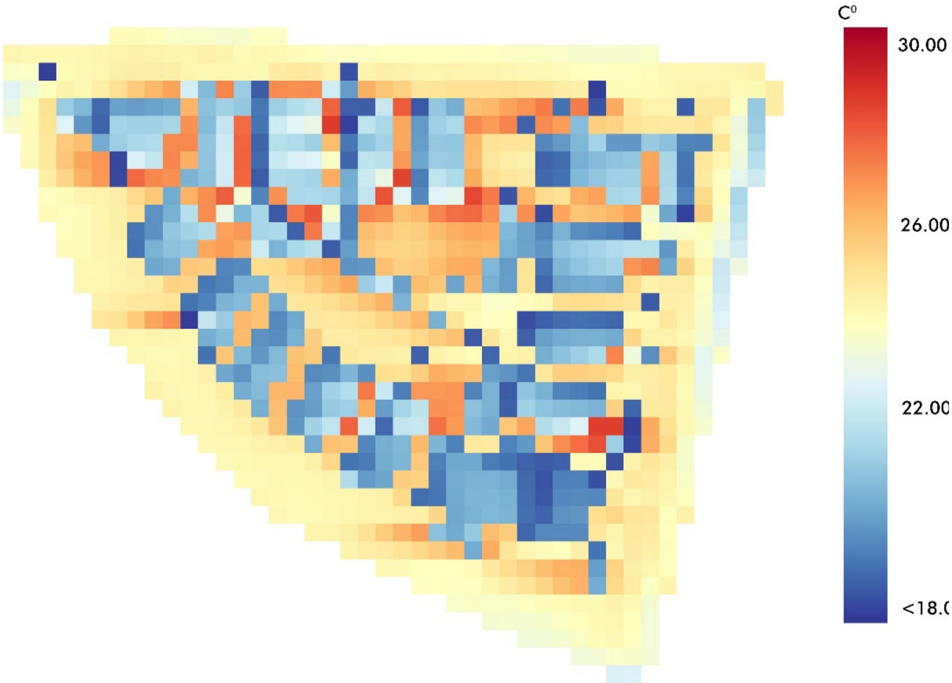

Figure 45. UTCI analysis at 9am.

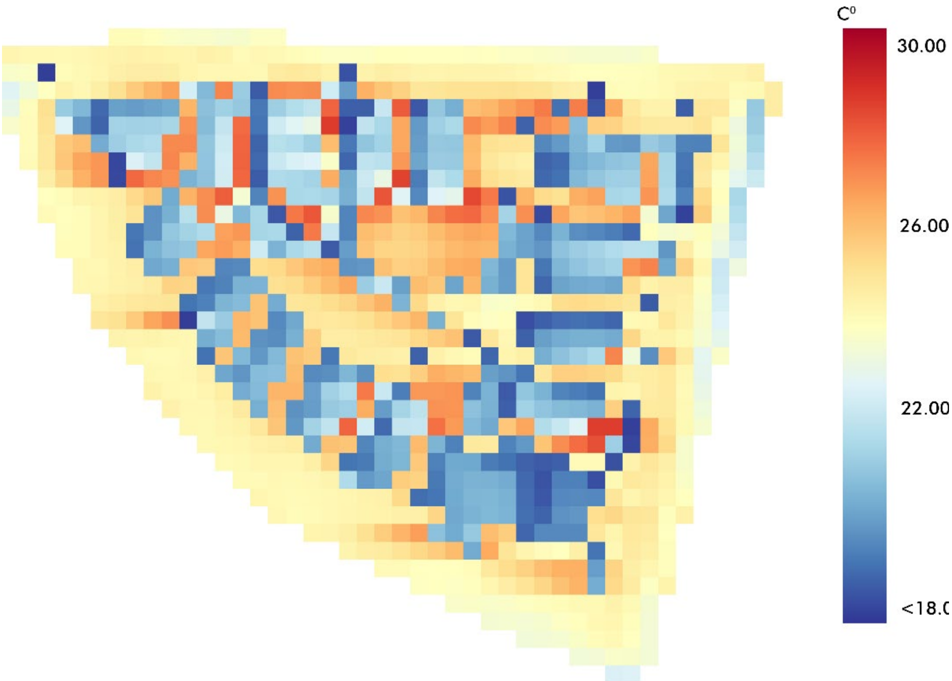

Figure 46. UTCI analysis at 1pm.

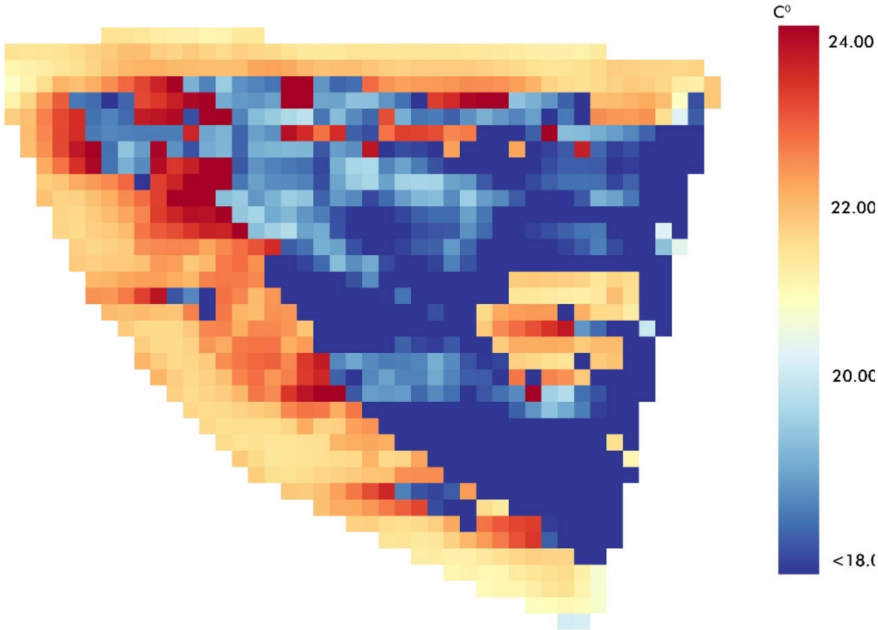

Figure 47. UTCI analysis at 5pm.

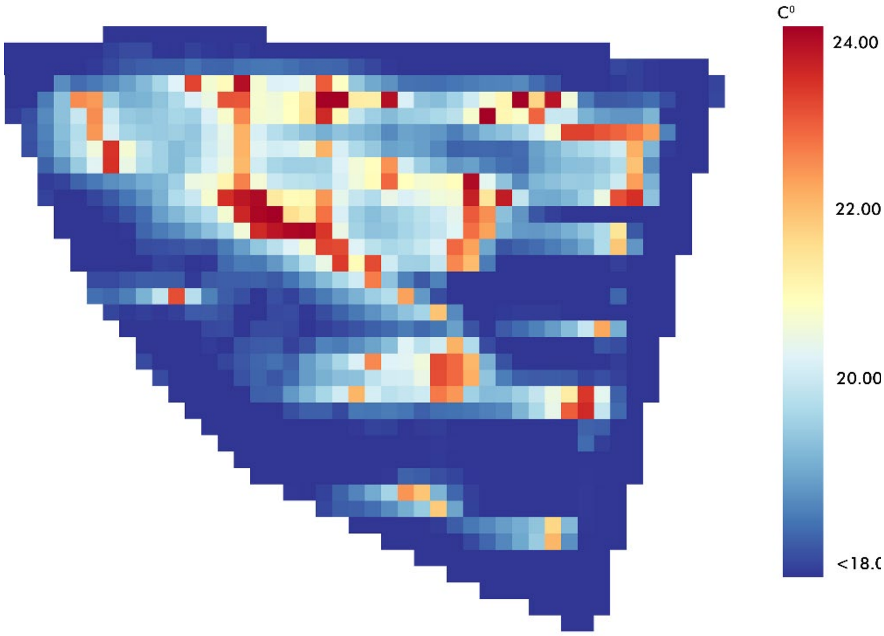

Figure 48. UTCI analysis at 9pm.

Runoff Depth

For the runoff depth calculation, Rainwater+ tool is used as explained in detail in 4.2.2.1.1. Land cover analysis is used as a reference for the surface types.

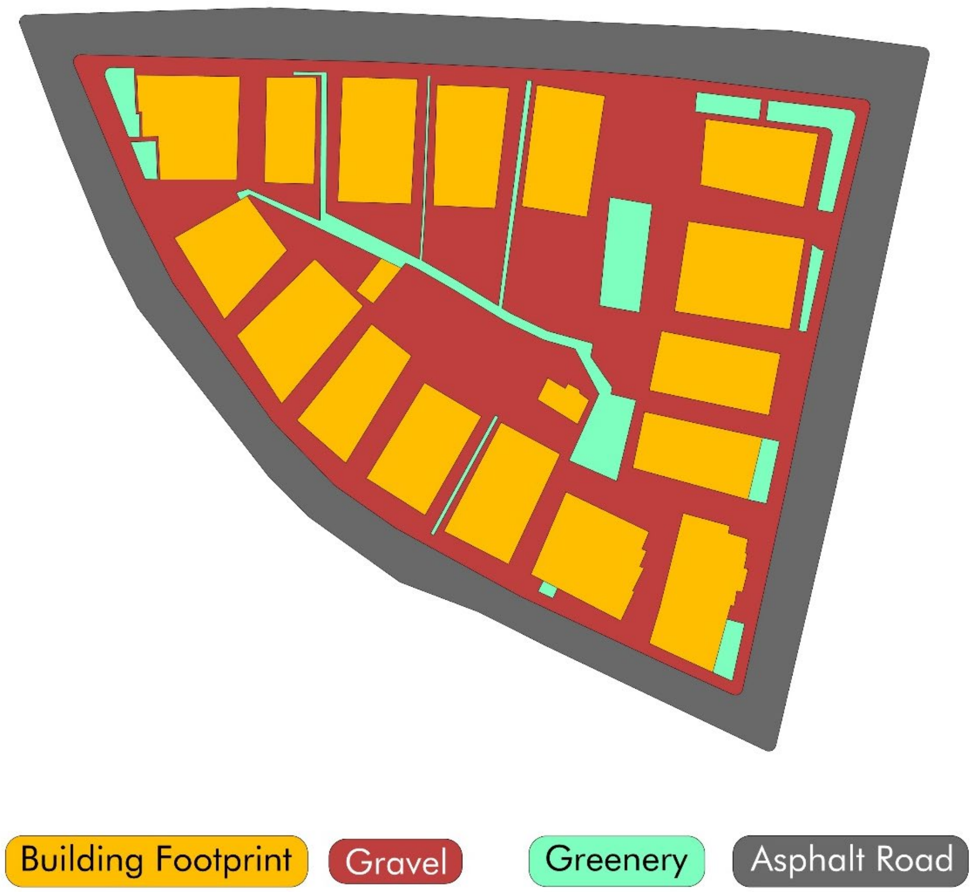

Figure 49. Land-use for water management.

Roofs are not included as a rain harvesting method but as an element redirecting the water flow with gutters. Waterspouts are important water outlets for the design of the treatments. However, waterspouts are not indicated in the model since the outlets can be redirected again in the design phase. Proximity analysis is used as a waterspout indication in that sense.

The Precipitation amount is taken from government's official weather forecast website (https://mgm.gov.tr/). However, since the daily precipitation amount is not indicated on the website, July's monthly total amount is divided by 30. Therefore, 0.47cm is used for daily precipitation amount to analyse of the runoff depth at the site.

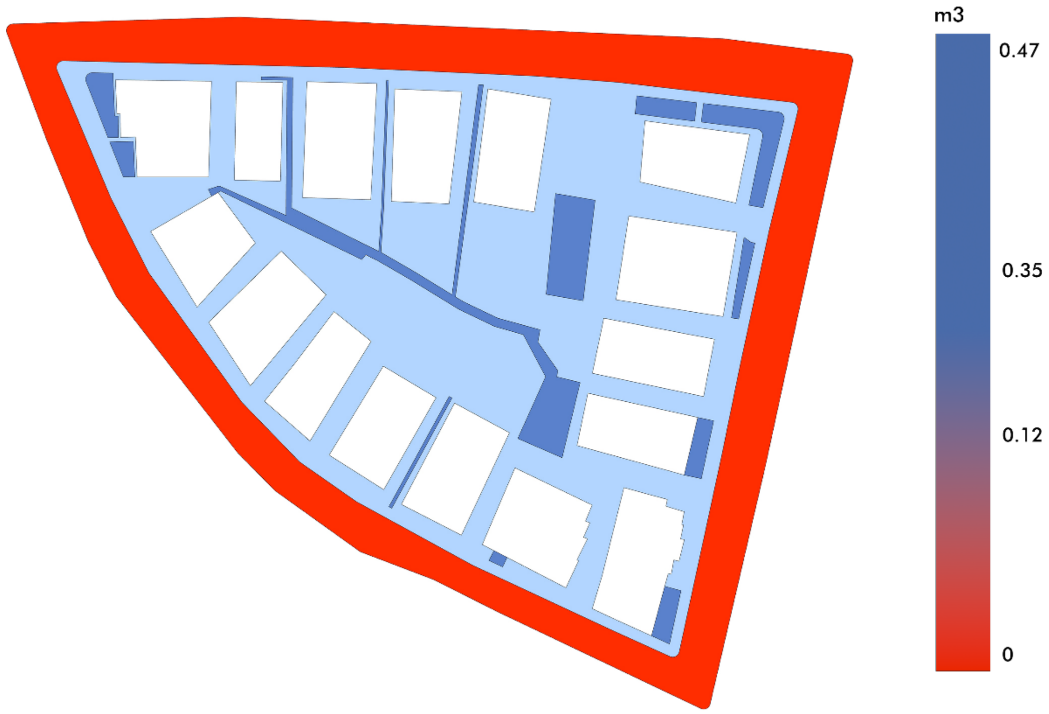

Figure 50. Runoff depth mapping of the site.

Figure 49. Runoff depth mapping of the site. shows the runoff depth based on surface differences and amount. Basically, areas with asphalt covers are much more runoff inefficient compared to other soft surfaces with greenery and gravel.

5.2.3 Scenario Selection

Ankara is in the interior high plateau of Turkey and has characteristics of the Csa Climate with warm and dry summers and long, cold and snowy winters. It can be broadly divided into two periods: the heating period, from October until the end of March and the cooling period, from April until September. On average, the warmest months are July and August, and the coolest month is January. indicates ninety-year climate data for Ankara.

Table 6. Ninety years of climate data for Ankara.

Turkish State Meteorological Service (www.mgm.gov.tr)

Climate data for Ankara (1927–2017)													
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	16.6 (61.9)	21.3 (70.3)	27.8 (82.0)	31.6 (88.9)	34.4 (93.9)	37.0 (98.6)	41.0 (105.8)	40.4 (104.7)	37.7 (99.9)	33.3 (91.9)	24.7 (76.5)	20.4 (68.7)	41.0 (105.8)
Average high °C (°F)	4.1 (39.4)	6.3 (43.3)	11.4 (52.5)	17.3 (63.1)	22.3 (72.1)	26.6 (79.9)	30.2 (86.4)	30.3 (86.5)	25.9 (78.6)	19.8 (67.6)	12.9 (55.2)	6.4 (43.5)	17.8 (64.0)
Daily mean °C (°F)	0.2 (32.4)	1.6 (34.9)	5.7 (42.3)	11.3 (52.3)	16.1 (61.0)	20.1 (68.2)	23.5 (74.3)	23.4 (74.1)	18.8 (65.8)	12.9 (55.2)	7.1 (44.8)	2.4 (36.3)	11.9 (53.4)
Average low °C (°F)	−3.3 (26.1)	−2.4 (27.7)	0.5 (32.9)	5.2 (41.4)	9.6 (49.3)	12.8 (55.0)	15.7 (60.3)	15.9 (60.6)	11.7 (53.1)	7.0 (44.6)	2.4 (36.3)	−0.8 (30.6)	6.2 (43.2)
Record low °C (°F)	−24.9 (−12.8)	−24.2 (−11.6)	−19.2 (−2.6)	−7.2 (19.0)	−1.6 (29.1)	3.8 (38.8)	4.5 (40.1)	5.5 (41.9)	−1.5 (29.3)	−9.8 (14.4)	−17.5 (0.5)	−24.2 (−11.6)	−24.9 (−12.8)
Average precipitation mm (inches)	39.5 (1.56)	35.0 (1.38)	38.6 (1.52)	42.3 (1.67)	51.2 (2.02)	34.2 (1.35)	13.7 (0.54)	11.5 (0.45)	17.8 (0.70)	27.6 (1.09)	31.7 (1.25)	43.9 (1.73)	387.0 (15.24)
Average precipitation days	12.1	11.1	10.7	11.0	12.1	8.4	3.4	2.6	4.0	6.8	8.0	11.6	101.8
Average relative humidity (%)	79	75	65	58	57	51	43	41	46	56	70	78	60
Mean monthly sunshine hours	83.7	110.2	161.2	195.0	263.5	303.0	353.4	334.8	276.0	207.7	138.0	77.5	2,504
Mean daily sunshine hours	2.7	3.9	5.2	6.5	8.5	10.1	11.4	10.8	9.2	6.7	4.6	2.5	6.8

Turkish State Meteorological Service states that the annual precipitation amount is 392mm. The rain pattern is typical of Anatolian climates. Ankara has significantly received less amount of rain compared to the Turkish's average yearly precipitation amount which is 522mm (www.mgm.gov.tr).

Table 7. Yearly climate data of Ankara.

Turkish State Meteorological Service (www.mgm.gov.tr)

ANKARA	Ocak	Şubat	Mart	Nisan	Mayıs	Haziran	Temmuz	Ağustos	Eylül	Ekim	Kasım	Aralık	Yıllık
	Ölçüm Periyodu (1927 - 2021)												
Ortalama Sıcaklık (°C)	0.2	1.7	5.7	11.2	16.1	20.0	23.4	23.4	18.9	13.2	7.3	2.5	12.0
Ortalama En Yüksek Sıcaklık (°C)	4.2	6.5	11.5	17.4	22.4	26.7	30.3	30.5	26.1	20.0	13.1	6.5	17.9
Ortalama En Düşük Sıcaklık (°C)	-3.2	-2.3	0.7	5.3	9.7	12.9	15.9	16.0	11.8	7.1	2.5	-0.8	6.3
Ortalama Güneşlenme Süresi (saat)	2.6	3.8	5.1	6.5	8.4	10.0	11.2	10.6	9.1	6.7	4.6	2.5	6.8
Ortalama Yağışlı Gün Sayısı	11.29	10.53	11.82	10.35	12.24	10.06	3.53	3.59	4.29	7.47	6.76	11.06	103.0
Aylık Toplam Yağış Miktarı Ortalaması (mm)	40.5	35.3	39.3	42.2	51.3	35.2	14.1	12.5	18.0	27.5	31.5	44.6	392.0
	Ölçüm Periyodu (1927 - 2021)												
En Yüksek Sıcaklık (°C)	18.4	21.3	27.8	31.6	34.4	37.0	41.0	40.4	39.1	33.3	24.7	20.4	41.0
En Düşük Sıcaklık (°C)	-24.9	-24.2	-19.2	-7.2	-1.6	3.8	4.5	5.5	-1.5	-9.8	-17.5	-24.2	-24.9

However, most of the rain is precipitated in narrow timelines as seen from Table 7. Yearly climate data of Ankara.. Therefore, it can be said that there is a flood risk due to high amount of rain a limited time. Moreover, the pervious surface amount is drastically high as seen from Figure 41. Land cover analysis. which is a parameter increasing the risk of flood. Contrary to that, high impervious ratio lets the water contaminate due to increased surface runoff time. Therefore, a scenario combination of filtration and detention should be applied to the case study. Filtration can help reduce runoff time and distance by increasing pervious surface rate. On the other hand, detention can be aimed to increase the area's water absorbing capacity to deal with high amounts of rains at certain times by holding excessive water.

Due to Ankara's high-paced, irregular and environmentally non-sensitive development, the increased rate of impervious surface creates a real threat for not only to water management but also thermal comfort of the city.

Table 8. Scenario weights for case study.

Pervious Surface	Street Tree	Rain Garden	Bioswale	Vegetated Buffers
1.5	1.5	1	1	1.25

Therefore, treatments associated with filtration are prioritized more than treatments for detention. The indicated Table 8. Scenario weights for case study. shows how the treatments are weighted for the case study in the next subsequent phases of the treatment proposition.

5.2.4 Patching

Patches are created with the system explained in 4.3 2D drawing of the study area (Figure 37. Study area in 2D.) is used as a reference for the buildings' arrangement, accessibility elements at the site and height differences. Unlike the sample model, the study had a sudden height difference dividing the backyards in two distinct flat areas. These areas are used as parking lots for residential buildings. Therefore, the height difference indicated in Figure 50. Sudden height difference at the site. with the red line is included in the patching system.

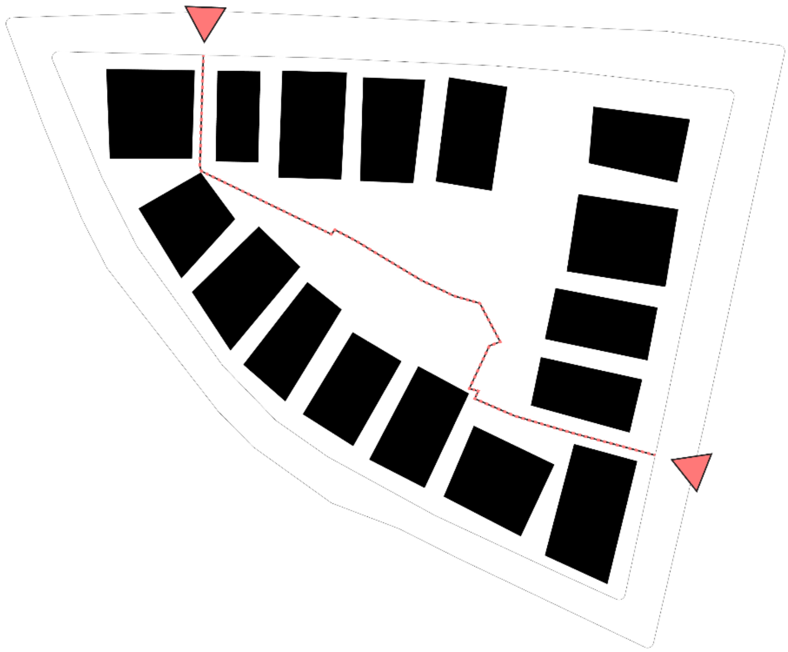

Figure 51. Sudden height difference at the site.

Figure 50. Sudden height difference at the site. shows the patches generated from 2D drawing. According to the study, there are 88 different patches at the site. According to the analysis, there are sixteen buildings, fourteen backyards, ten backyard neighbours, sixteen roads, sixteen fronts, sixteen in-betweens, sixteen front neighbours.

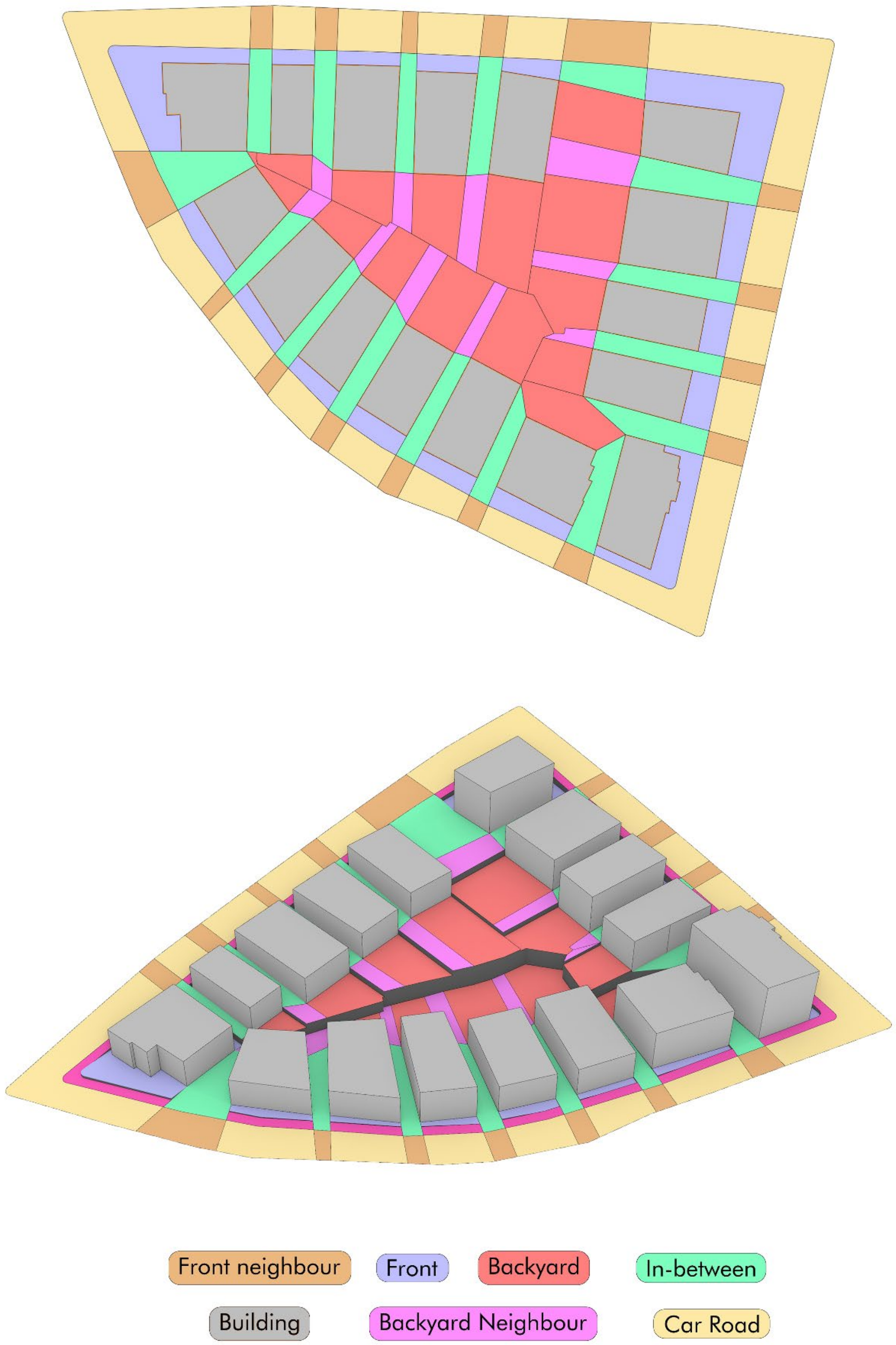

Figure 52. Patching system.

5.2.4.1 Physical Analysis

Based on the patches, physical conditions of the site are analysed.

Slope Analysis

The 3D modelled environment is used to calculate the average slopes of the patches. Since slope is calculated at a specific point, the average of the inclination degrees is used as a patches' slope coefficient.

Figure 52. Slope analysis of the site in 2D., shows the projected slope data onto the patches. The site has varying slopes at different locations.

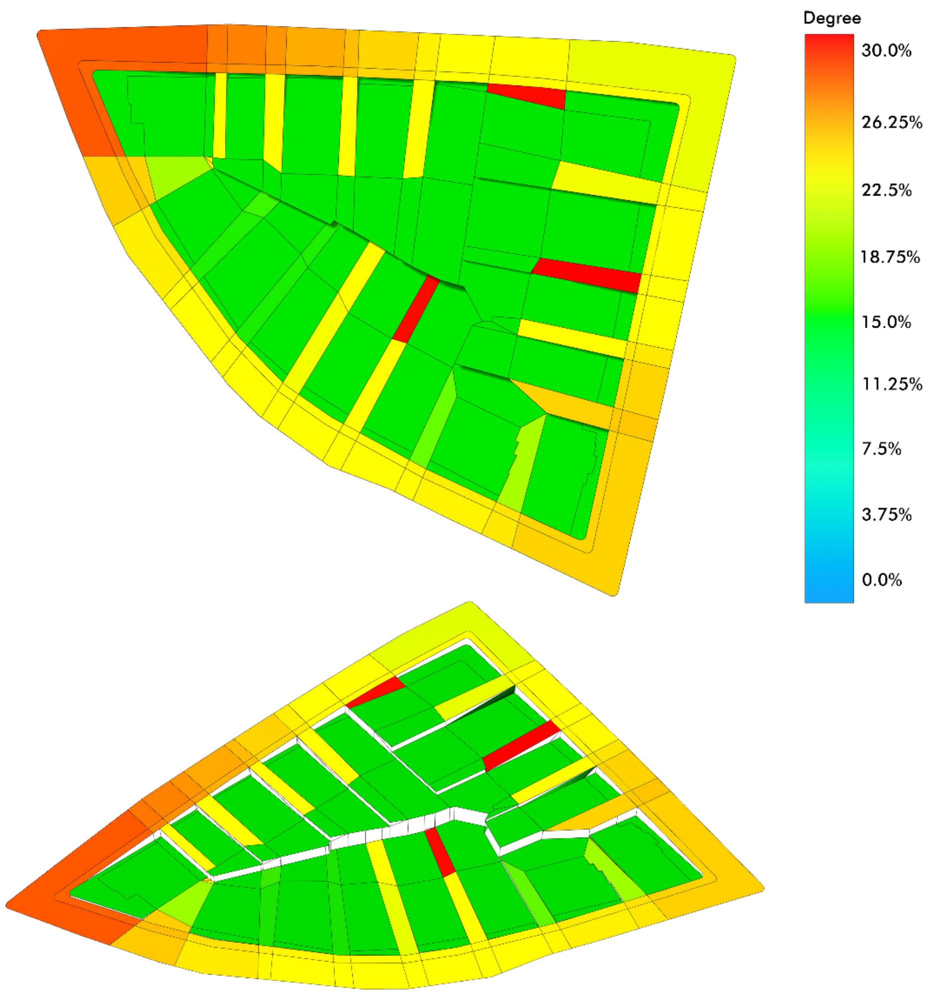

Figure 53. Slope analysis of the site in 2D.

Slope analysis shows the high inclination especially in the vehicular road. The backyards are between %3-5 due to the use as vehicular parking areas or being flattened during construction. However, the height difference between the road and the backyard patches, there is a slight inclination at the in-between patches. The strategy that should be followed in such area can be leading the running water to the bioswales to reduce the runoff in the vehicular roads while supporting the backs of the buildings with buffer zones and rain gardens to slowly infiltrate the water to the ground.

Proximity Analysis

Proximity to the buildings is analysed based on patches as explained in 4.2.3.2. The proximity of the patches to the closest building is calculated from its centre of mass to the closest curve as can be seen from the Figure 53. Centre of patches and closest building periphery.

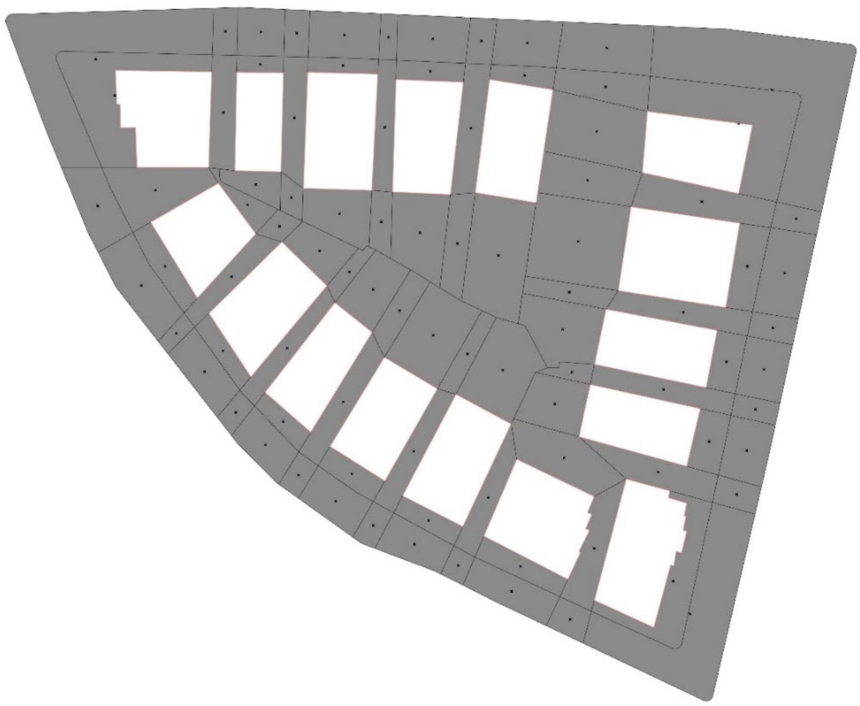

Figure 54. Centre of patches and closest building periphery.

Figure G shows the proximities of the patches to the closest building.

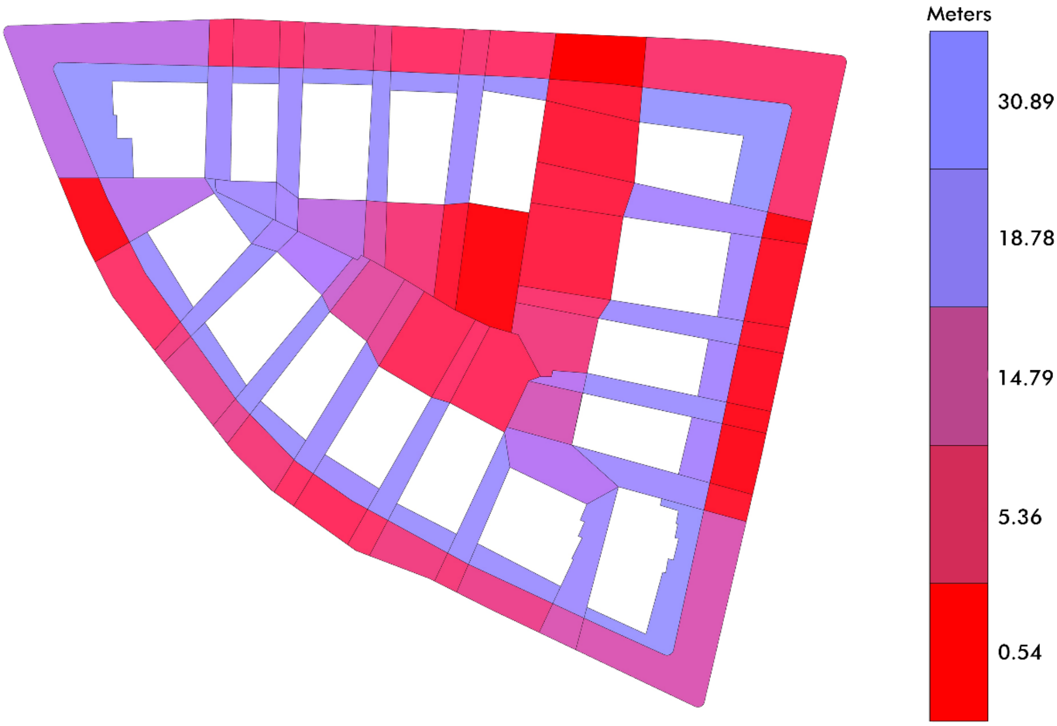

Figure 55. Proximity analysis of the site.

5.2.4.2 Projecting the Analysis onto Patches

The analysed conditions are projected onto the patches. These projections are used to calculate the coefficients of each patch in different data types based on matrix explained in 4.4.

Proximity and slope analysis are already projected onto patches and shown in 5.2.4.1. In this chapter, outdoor thermal comfort and runoff depth analysis are projected onto patches and shown in figures below.

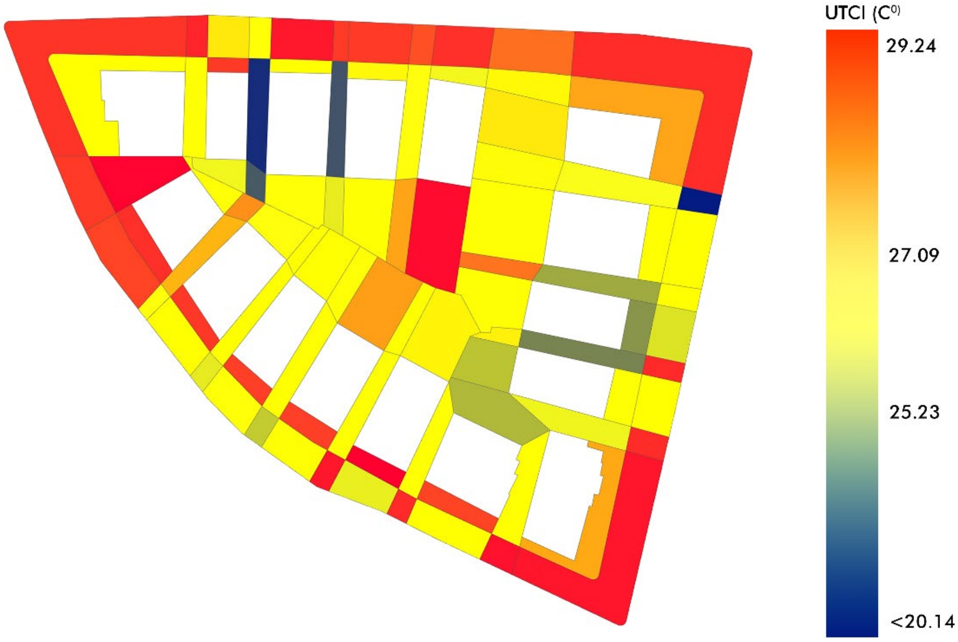

Figure 56. Projected UTCI values.

Due to limited calculation time for UTCI, only the 1pm results which are presented in Figure 45. UTCI analysis at 1pm. is projected onto the patches.

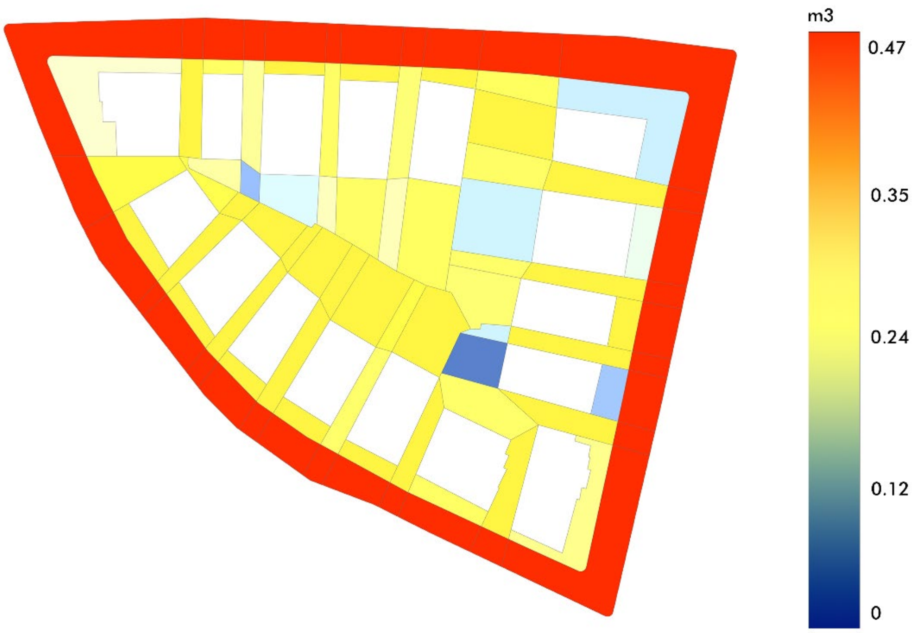

Figure 57. Projected runoff depth values.

5.2.5 Computationally Sorting Treatments

By using treatment matrix (4.4) and patches with projected data, available treatment list is sorted from the fittest choice to the weakest choice. Each patch’s total co-efficiency is calculated by finding which specific data belongs to the specific segment. Therefore, each patch is valued by mass adding the matches value.

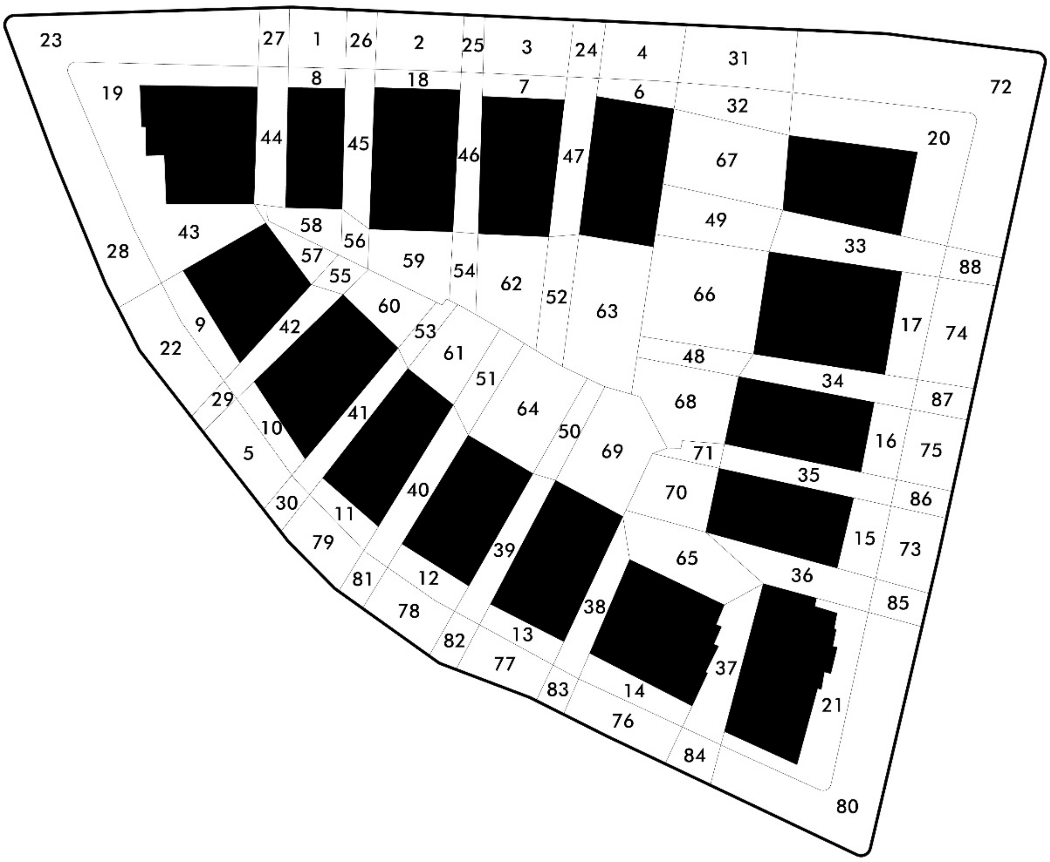

Figure 58. Patch numbers.

Treatments are numbered as shown in Table 9. Treatment's numbers.

Table 9. Treatment's numbers

1	Pervious Surface
2	Street Tree
3	Rain Garden
4	Bioswale
5	Vegetated Buffer

Error! Reference source not found. shows the lists of the values per treatment on the specific patch.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1. 4	1. 2	1. 2	1. 4	1. 1	1. 4	1. 1	1. 4	1. 4	1. 2
2. 0	2. 1	2. 1	2. 0	2. 3	2. 0	2. 2	2. 0	2. -1	2. 1
3. 3	3. 3	3. 2	3. 3	3. 3	3. 4	3. 5	3. 4	3. 4	3. 3
4. 5	4. 4	4. 4	4. 5	4. 5	4. 4	4. 5	4. 4	4. 5	4. 3
5. 3	5. 3	5. 3	5. 4	5. 4	5. 4	5. 4	5. 4	5. 4	5. 3
11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
1. 2	1. 1	1. 1	1. 1	1. 1	1. 1	1. 2	1. 1	1. 0	1. 0
2. 0	2. 2	2. 2	2. 3	2. 2	2. 2	2. 0	2. 0	2. 3	2. 3
3. 4	3. 4	3. 5	3. 4	3. 5	3. 5	3. 3	3. 4	3. 4	3. 4
4. 4	4. 5	4. 5	4. 4	4. 5	4. 5	4. 4	4. 3	4. 3	4. 3
5. 3	5. 4	5. 4	5. 4	5. 4	5. 4	5. 2	5. 2	5. 3	5. 3
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
1. 3	1. 1	1. 0	1. 1	1. 3	1. 2	1. 3	1. 1	1. 0	1. 0
2. -1	2. 3	2. 2	2. 1	2. 0	2. 1	2. 0	2. 1	2. 3	2. 3
3. 5	3. 3	3. 5	3. 3	3. 4	3. 2	3. 4	3. 2	3. 4	3. 3
4. 4	4. 5	4. 4	4. 3	4. 4	4. 4	4. 4	4. 3	4. 4	4. 4
5. 3	5. 3	5. 3	5. 2	5. 3	5. 2	5. 3	5. 2	5. 3	5. 3
31	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
1. 1	1. 1	1. 3	1. 0	1. 0	1. 0	1. 3	1. 2	1. 1	1. 0
2. 2	2. 3	2. -1	2. 2	2. 2	2. 2	2. -1	2. 1	2. 3	2. 2
3. 2	3. 4	3. 5	3. 4	3. 4	3. 5	3. 4	3. 3	3. 4	3. 5
4. 2	4. 5	4. 4	4. 4	4. 4	4. 4	4. 4	4. 3	4. 4	4. 4
5. 2	5. 3	5. 3	5. 3	5. 3	5. 3	5. 3	5. 2	5. 4	5. 3
41	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**
1. 1	1. 1	1. 4	1. 1	1. 4	1. 1	1. 0	1. 2	1. 1	1. 4
2. 0	2. 2	2. -1	2. 3	2. -1	2. 2	2. 2	2. 1	2. 4	2. 0
3. 4	3. 5	3. 4	3. 4	3. 5	3. 5	3. 5	3. 2	3. 3	3. 4
4. 3	4. 5	4. 5	4. 4	4. 5	4. 5	4. 4	4. 4	4. 4	4. 5
5. 2	5. 3	5. 3	5. 3	5. 3	5. 4	5. 3	5. 2	5. 3	5. 3
51	**52**	**53**	**54**	**55**	**56**	**57**	**58**	**59**	**60**
1. 1	1. 0	1. 3	1. 2	1. 1	1. 4	1. 2	1. 2	1. 2	1. 2
2. 3	2. 3	2. -1	2. 0	2. 2	2. 0	2. 0	2. 0	2. 0	2. 0
3. 3	3. 4	3. 5	3. 4	3. 4	3. 4	3. 3	3. 4	3. 4	3. 4
4. 5	4. 4	4. 4	4. 4	4. 5	4. 4	4. 4	4. 4	4. 4	4. 4
5. 3	5. 3	5. 3	5. 2	5. 3	5. 3	5. 3	5. 2	5. 3	5. 3
61	**62**	**63**	**64**	**65**	**66**	**67**	**68**	**69**	**70**
1. 2	1. 2	1. 2	1. 2	1. 2	1. 2	1. 2	1. 2	1. 1	1. 1
2. 1	2. 1	2. 1	2. 2	2. 1	2. 1	2. 1	2. 1	2. 1	2. 0
3. 2	3. 2	3. 2	3. 2	3. 3	3. 3	3. 2	3. 2	3. 3	3. 4
4. 4	4. 4	4. 4	4. 3	4. 3	4. 4	4. 4	4. 4	4. 3	4. 3
5. 3	5. 3	5. 3	5. 3	5. 3	5. 3	5. 3	5. 2	5. 2	5. 2
71	**72**	**73**	**74**	**75**	**76**	**77**	**78**	**79**	**80**
1. 2	1. 1	1. 2	1. 1	1. 1	1. 2	1. 2	1. 2	1. 2	1. 2
2. 0	2. 1	2. 1	2. 2	2. 1	2. 1	2. 2	2. 1	2. 2	2. 0
3. 4	3. 2	3. 3	3. 2	3. 2	3. 3	3. 2	3. 3	3. 2	3. 4
4. 4	4. 3	4. 4	4. 2	4. 3	4. 4	4. 3	4. 4	4. 3	4. 4
5. 2	5. 2	5. 2	5. 2	5. 2	5. 2	5. 2	5. 2	5. 2	5. 2
81	**82**	**83**	**84**	**85**	**86**	**87**	**88**		
1. 2	1. 2	1. 2	1. 2	1. 2	1. 2	1. 2	1. 2		
2. 1	2. 1	2. 1	2. 0	2. 1	2. 1	2. 1	2. 1		
3. 3	3. 3	3. 2	3. 4	3. 3	3. 2	3. 2	3. 3		
4. 4	4. 4	4. 4	4. 4	4. 4	4. 4	4. 4	4. 4		
5. 2	5. 2	5. 2	5. 3	5. 3	5. 3	5. 3	5. 3		

Figure 59. Patch's coefficient values per treatment.

Figure Y shows the sorted list of the treatments per patch.

1	2	3	4	5	6	7	8	9	10
1. Pervious Surface	1. Bioswale	1. Bioswale	1. Pervious Surface	1. Bioswale	1. Pervious Surface	1. Rain Garden	1. Pervious Surface	1. Pervious Surface	1. Vegetated Buffer
2. Bioswale	2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer	2. Bioswale	2. Vegetated Buffer	2. Vegetated Buffer	2. Pervious Surface
3. Vegetated Buffer	3. Pervious Surface	3. Pervious Surface	3. Bioswale	3. Street Tree	3. Rain Garden	3. Vegetated Buffer	3. Rain Garden	3. Bioswale	3. Rain Garden
4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Bioswale	4. Street Tree	4. Bioswale	4. Rain Garden	4. Bioswale
5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Street Tree	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Street Tree

11	12	13	14	15	16	17	18	19	20
1. Bioswale	1. Bioswale	1. Rain Garden	1. Vegetated Buffer	1. Rain Garden	1. Rain Garden	1. Bioswale	1. Rain Garden	1. Street Tree	1. Street Tree
2. Rain Garden	2. Vegetated Buffer	2. Bioswale	2. Street Tree	2. Bioswale	2. Bioswale	2. Rain Garden	2. Bioswale	2. Rain Garden	2. Rain Garden
3. Vegetated Buffer	3. Rain Garden	3. Vegetated Buffer	3. Rain Garden	3. Vegetated Buffer	3. Vegetated Buffer	3. Pervious Surface	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer
4. Pervious Surface	4. Street Tree	4. Street Tree	4. Bioswale	4. Street Tree	4. Street Tree	4. Vegetated Buffer	4. Pervious Surface	4. Bioswale	4. Bioswale
5. Street Tree	5. Pervious Surface	5. Pervious Surface	5. Pervious Surface	5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Pervious Surface

21	22	23	24	25	26	27	28	29	30
1. Rain Garden	1. Bioswale	1. Rain Garden	1. Bioswale	1. Pervious Surface	1. Bioswale	1. Pervious Surface	1. Bioswale	1. Street Tree	1. Street Tree
2. Pervious Surface	2. Street Tree	2. Bioswale	2. Rain Garden	2. Rain Garden	2. Pervious Surface	2. Rain Garden	2. Vegetated Buffer	2. Bioswale	2. Bioswale
3. Bioswale	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer	3. Bioswale	3. Vegetated Buffer	3. Bioswale	3. Rain Garden	3. Rain Garden	3. Vegetated Buffer
4. Vegetated Buffer	4. Rain Garden	4. Street Tree	4. Pervious Surface	4. Vegetated Buffer	4. Rain Garden	4. Vegetated Buffer	4. Pervious Surface	4. Vegetated Buffer	4. Rain Garden
5. Street Tree	5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Pervious Surface

31	32	33	34	35	36	37	38	39	40
1. Street Tree	1. Bioswale	1. Rain Garden	1. Bioswale	1. Bioswale	1. Rain Garden	1. Pervious Surface	1. Rain Garden	1. Vegetated Buffer	1. Rain Garden
2. Vegetated Buffer	2. Street Tree	2. Pervious Surface	2. Rain Garden	2. Rain Garden	2. Bioswale	2. Rain Garden	2. Bioswale	2. Street Tree	2. Bioswale
3. Rain Garden	3. Rain Garden	3. Bioswale	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer	3. Bioswale	3. Pervious Surface	3. Rain Garden	3. Vegetated Buffer
4. Bioswale	4. Vegetated Buffer	4. Vegetated Buffer	4. Street Tree	4. Street Tree	4. Street Tree	4. Vegetated Buffer	4. Vegetated Buffer	4. Bioswale	4. Street Tree
5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Pervious Surface	5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Pervious Surface

41	42	43	44	45	46	47	48	49	50
1. Rain Garden	1. Bioswale	1. Pervious Surface	1. Street Tree	1. Pervious Surface	1. Rain Garden	1. Rain Garden	1. Bioswale	1. Street Tree	1. Pervious Surface
2. Bioswale	2. Rain Garden	2. Bioswale	2. Bioswale	2. Rain Garden	2. Bioswale	2. Bioswale	2. Pervious Surface	2. Bioswale	2. Bioswale
3. Vegetated Buffer	3. Vegetated Buffer	3. Rain Garden	3. Rain Garden	3. Bioswale	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer	3. Rain Garden
4. Pervious Surface	4. Street Tree	4. Vegetated Buffer	4. Vegetated Buffer	4. Vegetated Buffer	4. Street Tree	4. Street Tree	4. Rain Garden	4. Rain Garden	4. Vegetated Buffer
5. Street Tree	5. Pervious Surface	5. Street Tree	5. Pervious Surface	5. Street Tree	5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Pervious Surface	5. Street Tree

51	52	53	54	55	56	57	58	59	60
1. Bioswale	1. Street Tree	1. Rain Garden	1. Bioswale	1. Bioswale	1. Pervious Surface	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale
2. Street Tree	2. Bioswale	2. Pervious Surface	2. Rain Garden	2. Rain Garden	2. Rain Garden	2. Vegetated Buffer	2. Rain Garden	2. Rain Garden	2. Rain Garden
3. Vegetated Buffer	3. Rain Garden	3. Bioswale	3. Pervious Surface	3. Vegetated Buffer	3. Bioswale	3. Pervious Surface	3. Pervious Surface	3. Vegetated Buffer	3. Vegetated Buffer
4. Rain Garden	4. Vegetated Buffer	4. Vegetated Buffer	4. Vegetated Buffer	4. Street Tree	4. Vegetated Buffer	4. Rain Garden	4. Vegetated Buffer	4. Pervious Surface	4. Pervious Surface
5. Pervious Surface	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree

61	62	63	64	65	66	67	68	69	70
1. Bioswale	1. Bioswale	1. Bioswale	1. Vegetated Buffer	1. Vegetated Buffer	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale	1. Rain Garden
2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer	2. Street Tree	2. Pervious Surface	2. Vegetated Buffer	2. Vegetated Buffer	2. Pervious Surface	2. Rain Garden	2. Bioswale
3. Pervious Surface	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface	3. Rain Garden	3. Pervious Surface	3. Pervious Surface	3. Vegetated Buffer	3. Vegetated Buffer	3. Vegetated Buffer
4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Bioswale	4. Bioswale	4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Pervious Surface	4. Pervious Surface
5. Street Tree	5. Street Tree	5. Street Tree	5. Rain Garden	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree

71	72	73	74	75	76	77	78	79	80
1. Bioswale	1. Bioswale	1. Bioswale	1. Street Tree	1. Bioswale	1. Bioswale	1. Street Tree	1. Bioswale	1. Street Tree	1. Bioswale
2. Rain Garden	2. Vegetated Buffer	2. Rain Garden	2. Vegetated Buffer	2. Vegetated Buffer	2. Rain Garden	2. Bioswale	2. Rain Garden	2. Bioswale	2. Rain Garden
3. Pervious Surface	3. Rain Garden	3. Pervious Surface	3. Rain Garden	3. Rain Garden	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface
4. Vegetated Buffer	4. Pervious Surface	4. Vegetated Buffer	4. Bioswale	4. Pervious Surface	4. Vegetated Buffer	4. Vegetated Buffer	4. Vegetated Buffer	4. Vegetated Buffer	4. Vegetated Buffer
5. Street Tree	5. Street Tree	5. Street Tree	5. Pervious Surface	5. Street Tree	5. Street Tree	5. Rain Garden	5. Street Tree	5. Rain Garden	5. Street Tree

81	82	83	84	85	86	87	88
1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale	1. Bioswale
2. Rain Garden	2. Rain Garden	2. Pervious Surface	2. Rain Garden	2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer	2. Vegetated Buffer
3. Pervious Surface	3. Pervious Surface	3. Vegetated Buffer	3. Vegetated Buffer	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface	3. Pervious Surface
4. Vegetated Buffer	4. Vegetated Buffer	4. Rain Garden	4. Pervious Surface	4. Rain Garden	4. Rain Garden	4. Rain Garden	4. Rain Garden
5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree	5. Street Tree

Figure 60. Value based sorted treatment list per patch.

The best fit is projected onto the patch on Figure 60. Best fit for the patches projected on 2D mapping..

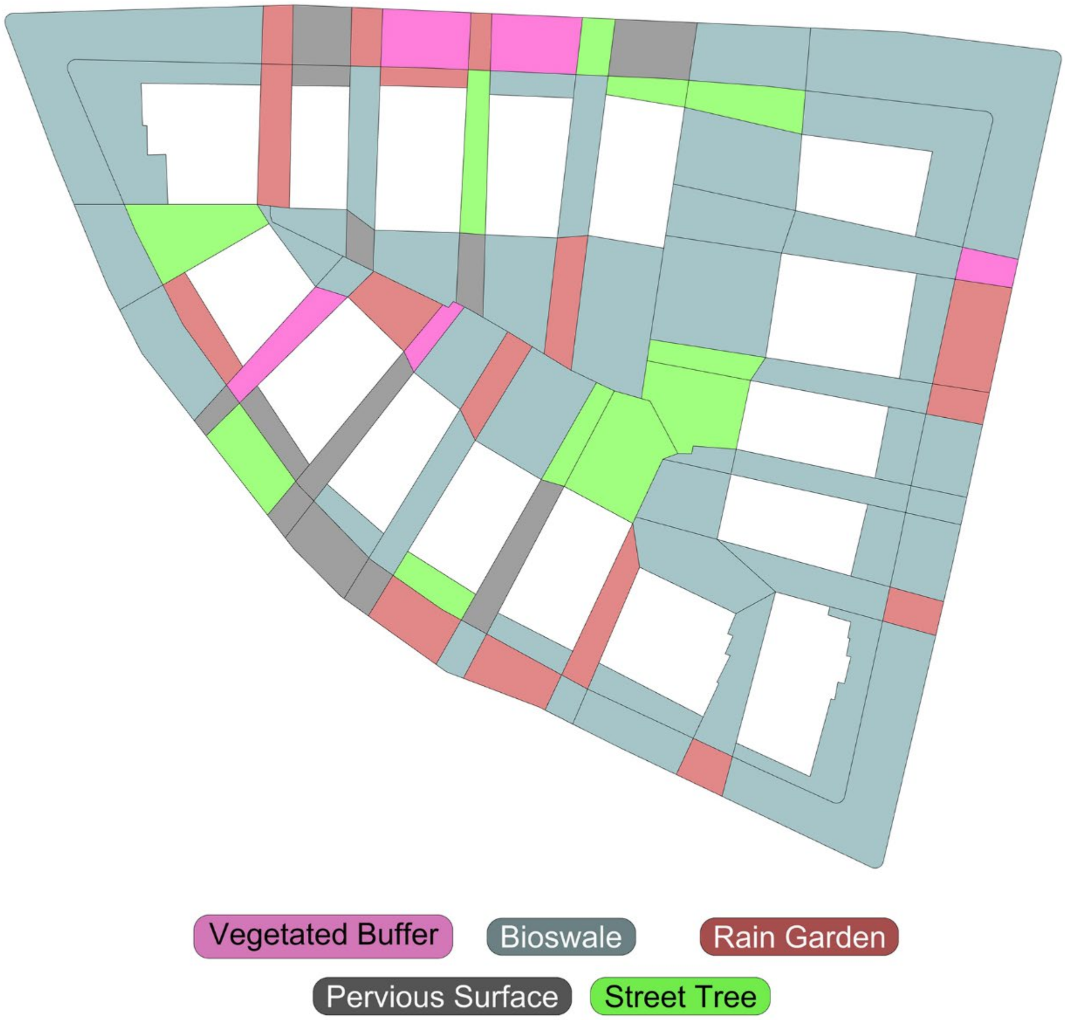

Figure 61. Best fit for the patches projected on 2D mapping.

According to the sorting, there are twelve pervious surfaces, eleven street trees, five vegetated buffers, sixteen raingardens and forty-four bioswales for eighty eight patches.

5.2.6 Defining Type of Treatment with Patch and Context Information

The algorithmically sorted treatments are used as a basis for the design stage. However, due to the complex structure of urban context and sorting algorithm lacking every detail that needs to be considered the changes indicated below are applied in the design stage.

1. Patch 19, bioswale to street tree. Due to its strategic location at the corner of the buildings and an open area covered with social places such as cafes this area is considered with street trees to make a meeting point. Moreover, this patch directly faces the sun and open to excessive heats during the summer. Therefore, the area is supported with shade and open space.

Figure 62. Patch 19's existing view.

2. Patch 63, bioswale to street tree. Like change on Patch 19, this patch is taking direct sun from the south. In contrary to that, there are three more street tree patches nearby. Therefore, connecting these areas to create shade and open to the public can be an essential asset for the site's future development for the habitants. Moreover, the site has a large ratio of impervious surface which

is tends to collect heat. Street trees may prevent the surface from overheating during long sun exposures.

Figure 63. Existing condition of Patch 63.

3. Patch 72, bioswale to vegetated buffer.Since this patch has one of the slightest inclination in the road segment and is at the top of the site, creating a barrier that can slow down the water rather than collecting could have been more beneficial. Moreover, this patch is at the corner and pedestrian way.

Therefore, introducing greenery with different plants with visual attraction can be a more delitable experience for the pedestrians.

Figure 64. Existing condition of Patch 72 (Google Maps).

4. Patch 5, street tree to pervious surface. Although this patch takes direct sunlight from the south and is thermally close to being uncomfortable during hot days, the building close to this patch has been used as night club for a long time. Despite being closed, this night club can be turned into a social place where people gather in front and around of the building. Therefore, rather than trees, creating open area with hard surface would be much more suitable for the development of this area.

Figure 65. Existing condition of the abandoned building in front of Patch 5 (Google Maps).

5. **5.** Patch 60, bioswale to pervious surface. Like Patch 5, this patch is behind the abandoned building shown in Figure 64. Existing condition of the abandoned building in front of Patch 5 (Google Maps). Therefore, considering the social interaction that is planned to be around the building, this patch is changed to pervious surface as well as Patch 5.

The rest of the surfaces do not threat a context-based problem. Therefore, they all are accepted as suggested as the output of the approach steps. The final decisions upon the patches are shown below in Figure 65. Final treatment decisions..

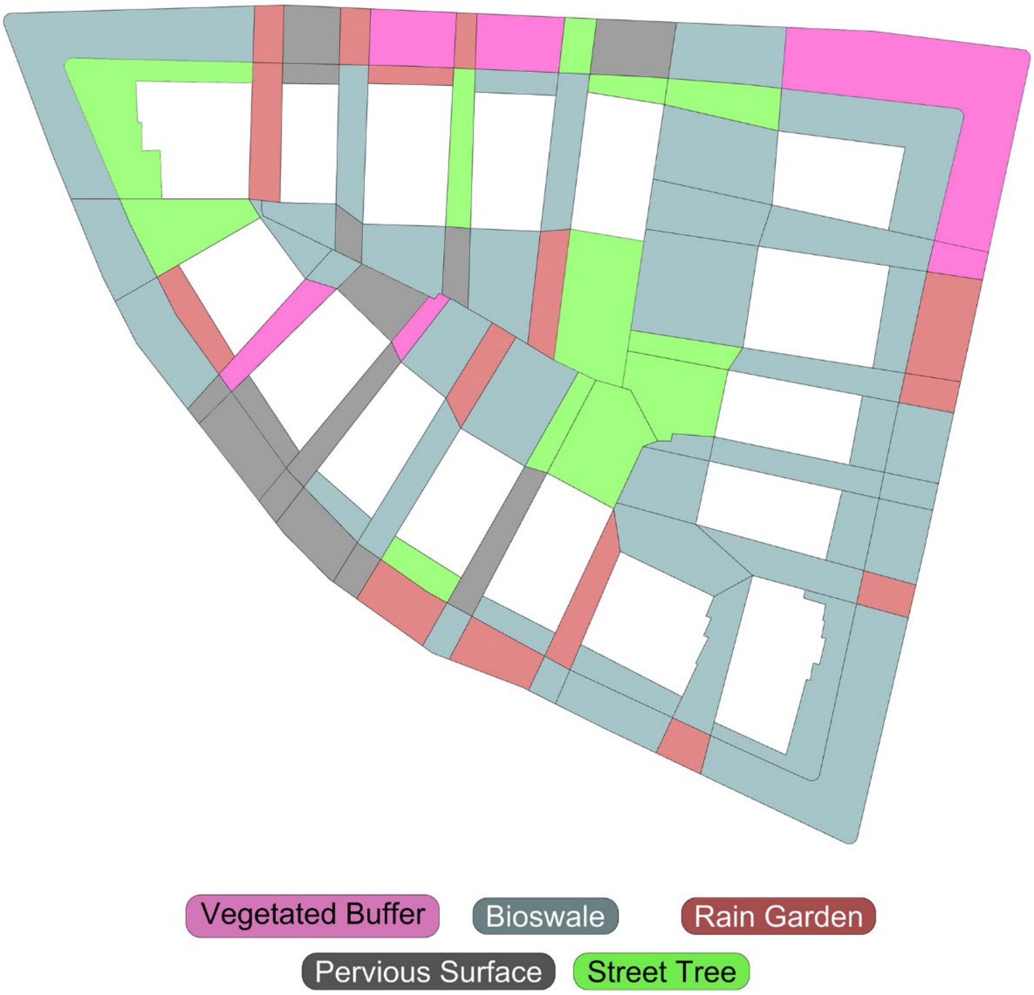

Figure 66. Final treatment decisions.

5.2.7 Designing with the Decided Treatments

The proposed and re-evaluated scheme of treatments are applied to the case study by the author to show the further implementation of the treatments and highlight the key differences of methods and details in the implementation phase. Therefore, the area is evaluated based on previous observations both based on quantitative and qualitative analysis.

While designing, these key criteria are followed not obligatorily but majorly:

1. Interventions to vehicular roads are limited to vehicular strip amounts and ways. One way of vehicular road is taken as 3 meters of wide. Therefore, two sided roads are planned as 6 meters of wide as minimum dimensions. The interventions at the side of the roads are designed according to these dimensions (Neufert, 2019).
2. Although pavement is indicated clearly in the municipality drawings, most of the pavements are occupied by the business owners. Therefore, while designing the pedestrian passages and pavements, municipality drawing is accepted as master plan. 2 meters of width is separated for pedestrian accessibility and rest of the pavements are designed with the proposed treatments.
3. Bioswales and raingardens which act like strips to collect rooftop rainwater designed with 2 meters of width as minimum dimensions for the effective implementation of the treatment.
4. By sticking with the proposed treatments, one of the main aims of the design phase is connecting the treatments to each other to minimize the runoff amount and deliver the water to the available areas. Therefore, maximum connectivity amongst the treatments is aimed at.

In the light of these criteria, the proposed early design scheme for the study area is shown in Figure 66. Proposed early design scheme. The existing condition can be visited in Figure 37. Study area in 2D..

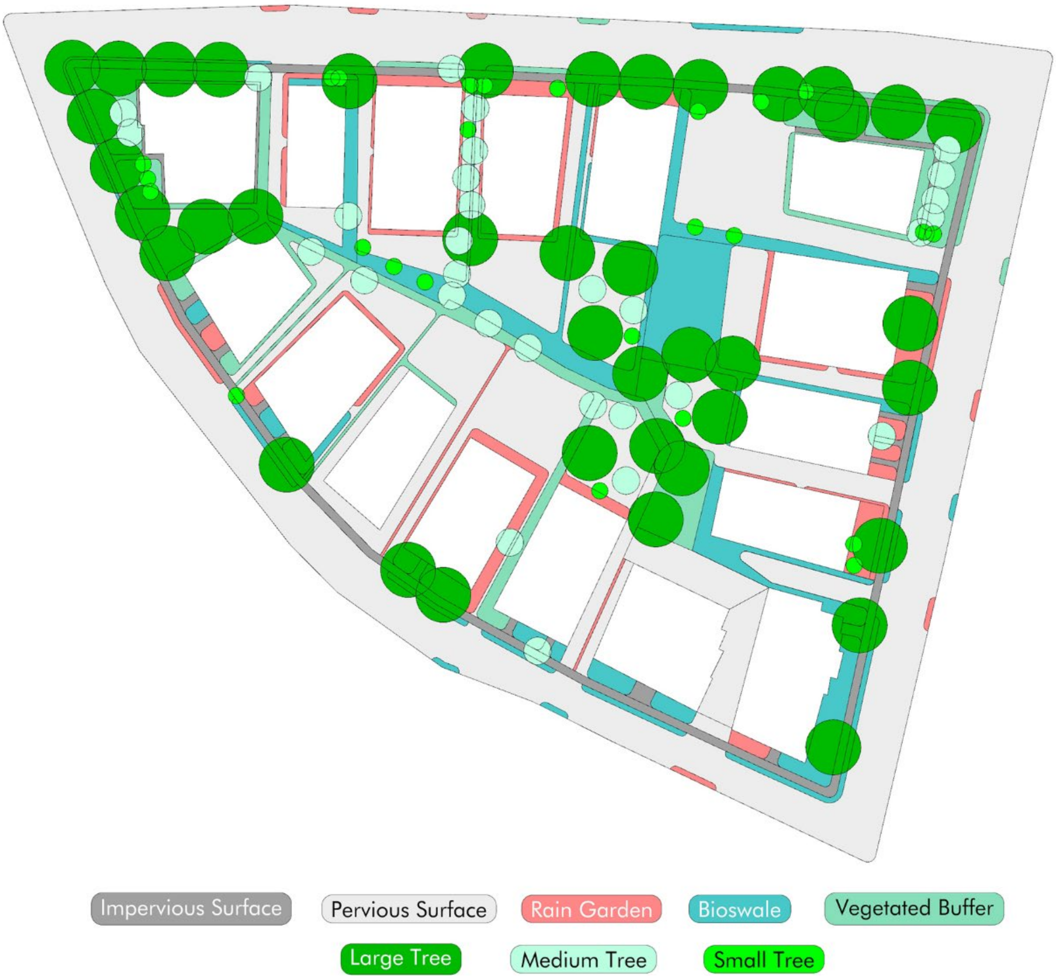

Figure 67. Proposed early design scheme for the study area

While designing, porosity in hard surfaces such as vehicular roads, parking lots and in between roads are considered as pervious surfaces since these areas cover huge lands and the travel distance is much larger compared to hard surfaces such as pavements which are accompanied by green lots all the time. Pavements that are mainly used for pedestrian accessibility are not consider as pervious surface since the aesthetic and functional choices are limited in pervious surface selection. Therefore, for the well-being of habitants, pavement surfaces are considered as impervious surfaces to deliver more choices in the later stages.

Trees are scattered along with propositions and for maximum shade during positioning. All the existing trees are preserved, and new trees are added accordingly. The surface below the trees is designed so that programs can be further integrated under the trees. In addition to that, closest surface types are linked within these surfaces under the trees. Figure 67. Ground layout of scheme. can be investigated for further investigation of the ground floor.

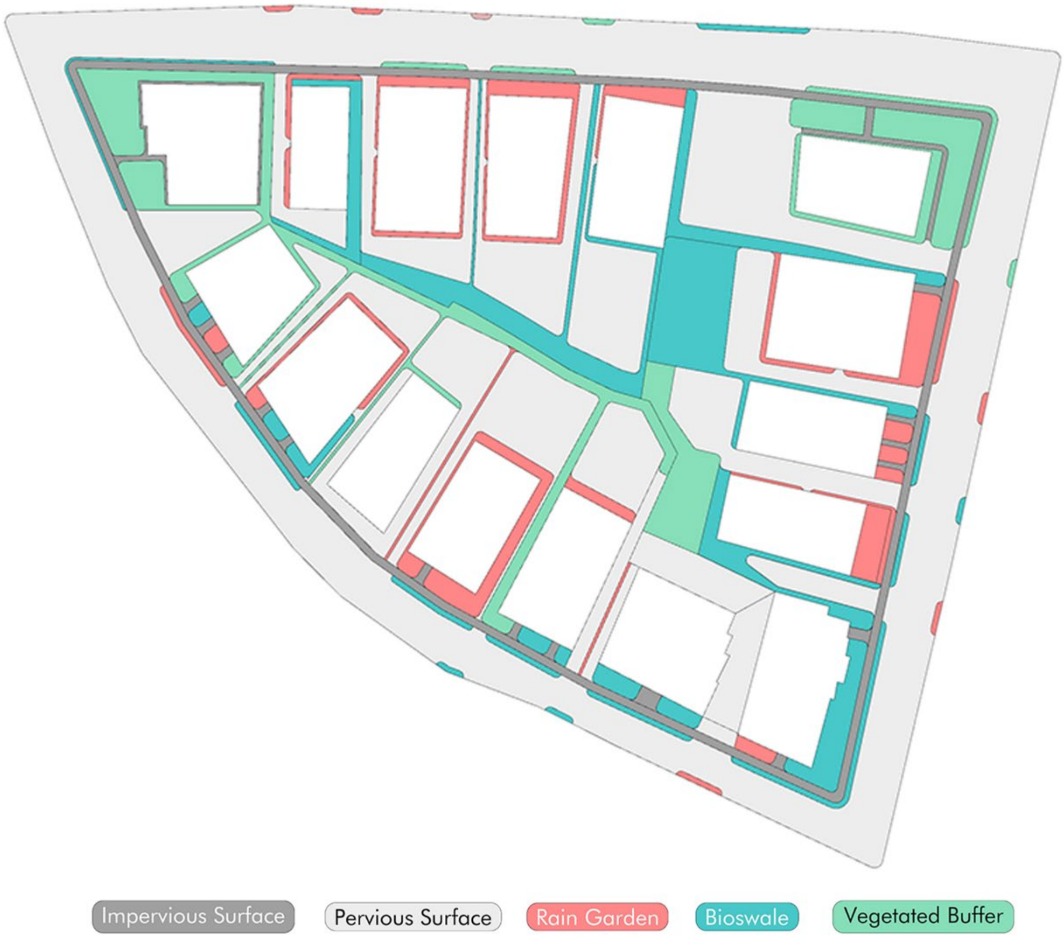

Figure 68. Ground layout of scheme.

Thin strips between the houses which are common throughout the site and a local method to both separate the two property and provide privacy, are extended towards the treatments, and expanded in width to become effective while dealing with outdoor thermal comfort and acting as barriers during excessive rains.

5.3 Re-evaluating the Proposed Condition

The proposed early design scheme aims to reduce the runoff amount while improving the outdoor thermal comfort throughout the study area. Previous methods explained in 4.2.2.1 is used again to understand the changes in performance with the interventions. Later, results are discussed based on approach framework and treatment selection.

5.3.1 Runoff Analysis

The most important aim for the approach is to decrease the amount of runoff rainwater to prevent several problems explained in Chapter 2.

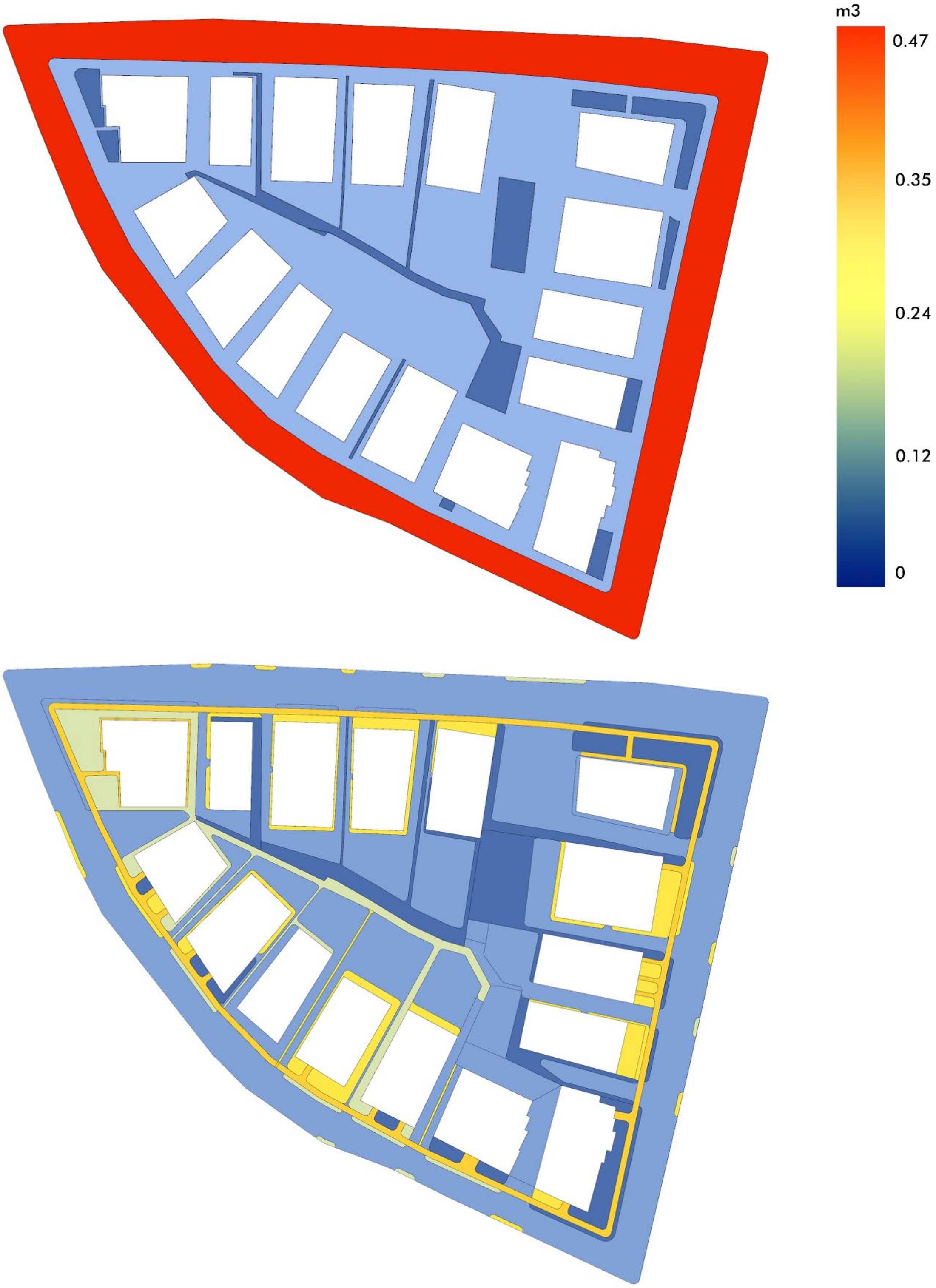

Figure 69. Comparison of runoff amounts.

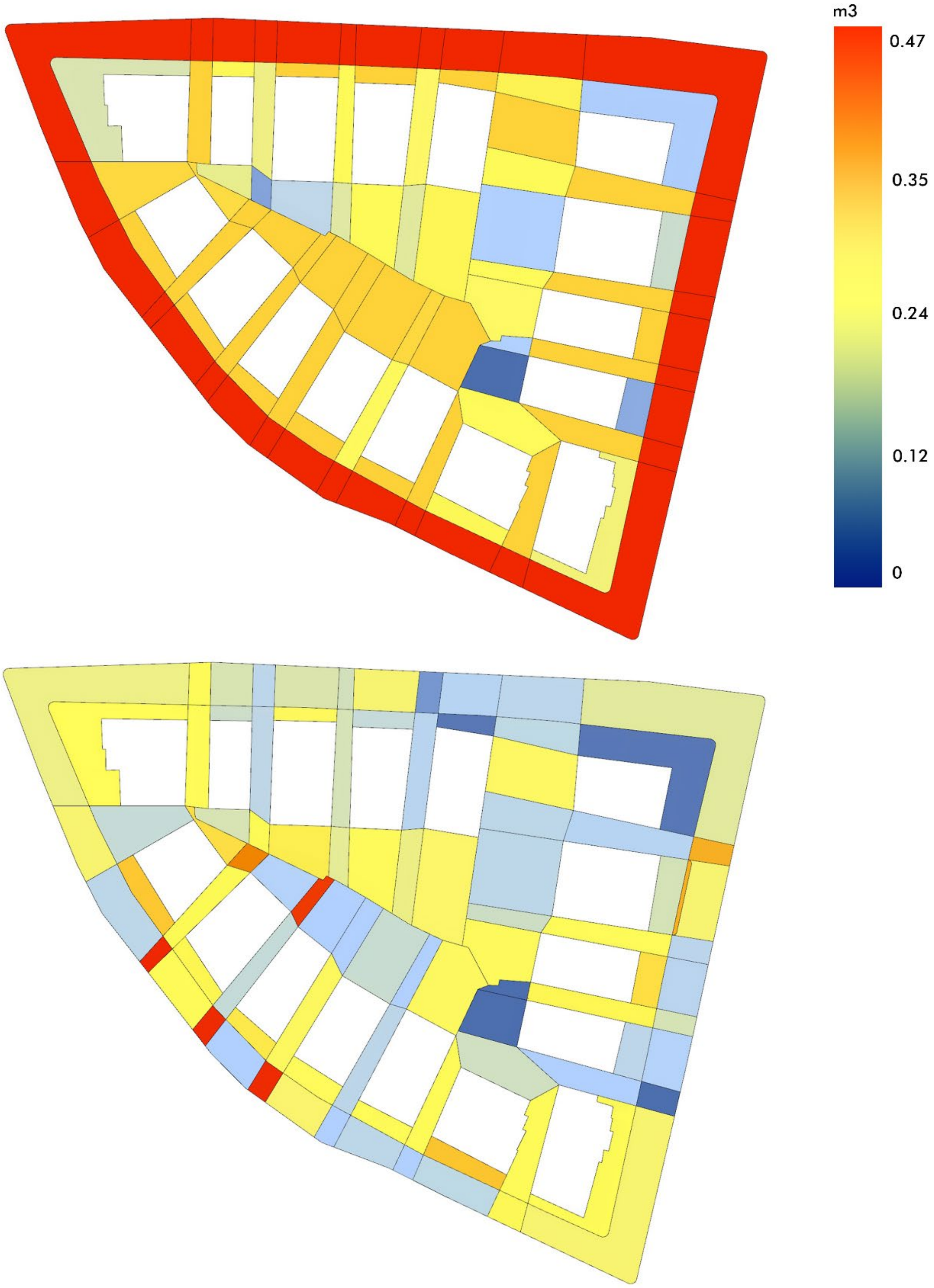

Figure 70. Runoff analysis projected onto the patches for comparison.

5.3.2 Outdoor Thermal Comfort Analysis

Aside from the drastic effects of treatments on decreasing runoff water, it is also aimed by the approach to increase outdoor thermal comfort. Same calculation method and environment is used for calculating the outdoor thermal comfort performance of the proposed design scheme. ENVI-MET is used in the same area with the same weather data and date. Therefore, the same conditions are created for different physical environments to compare only the changes.

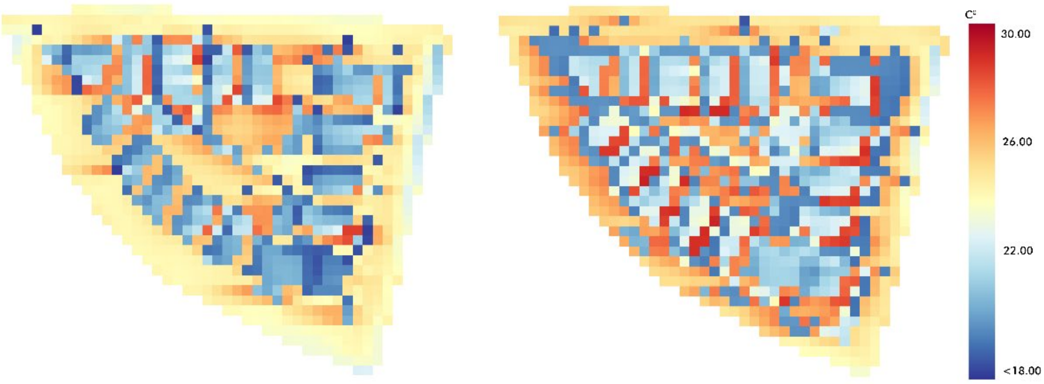

Figure 71. UTCI Comparison at 9am.

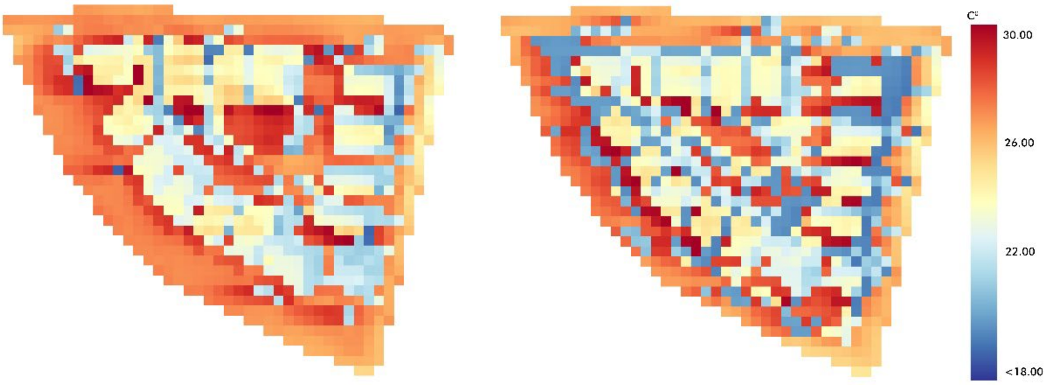

Figure 72.UTCI Comparison at 1pm.

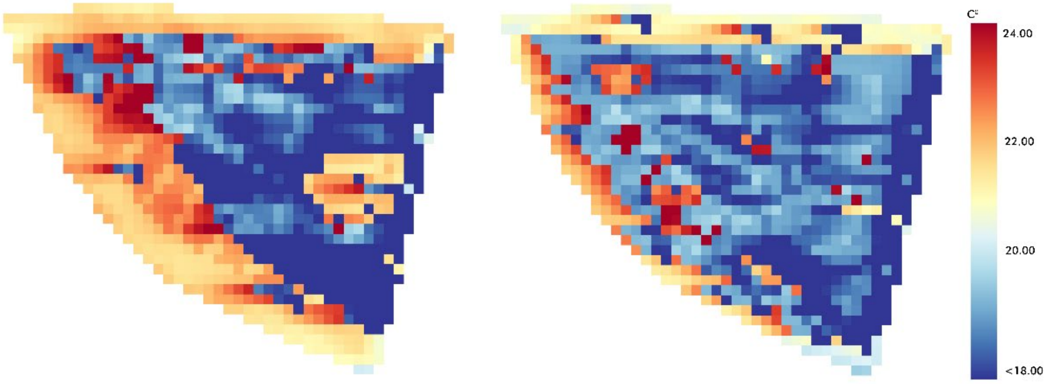

Figure 73. UTCI Comparison at 5pm.

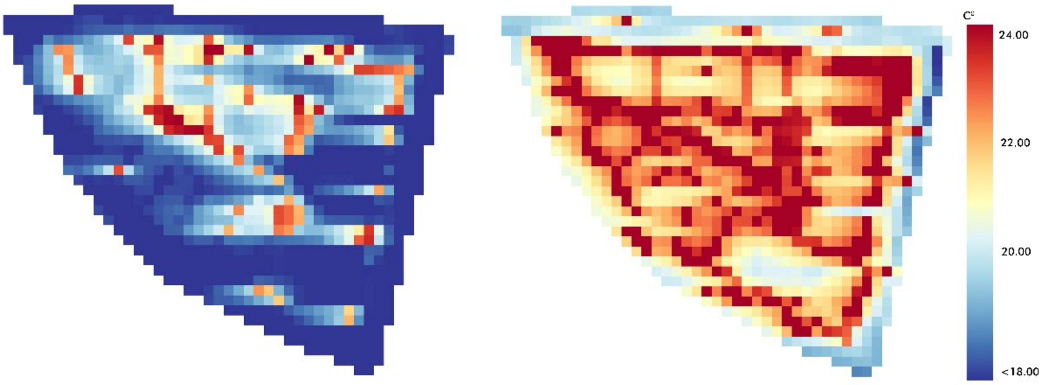

Figure 74. UTCI Comparison at 9pm.

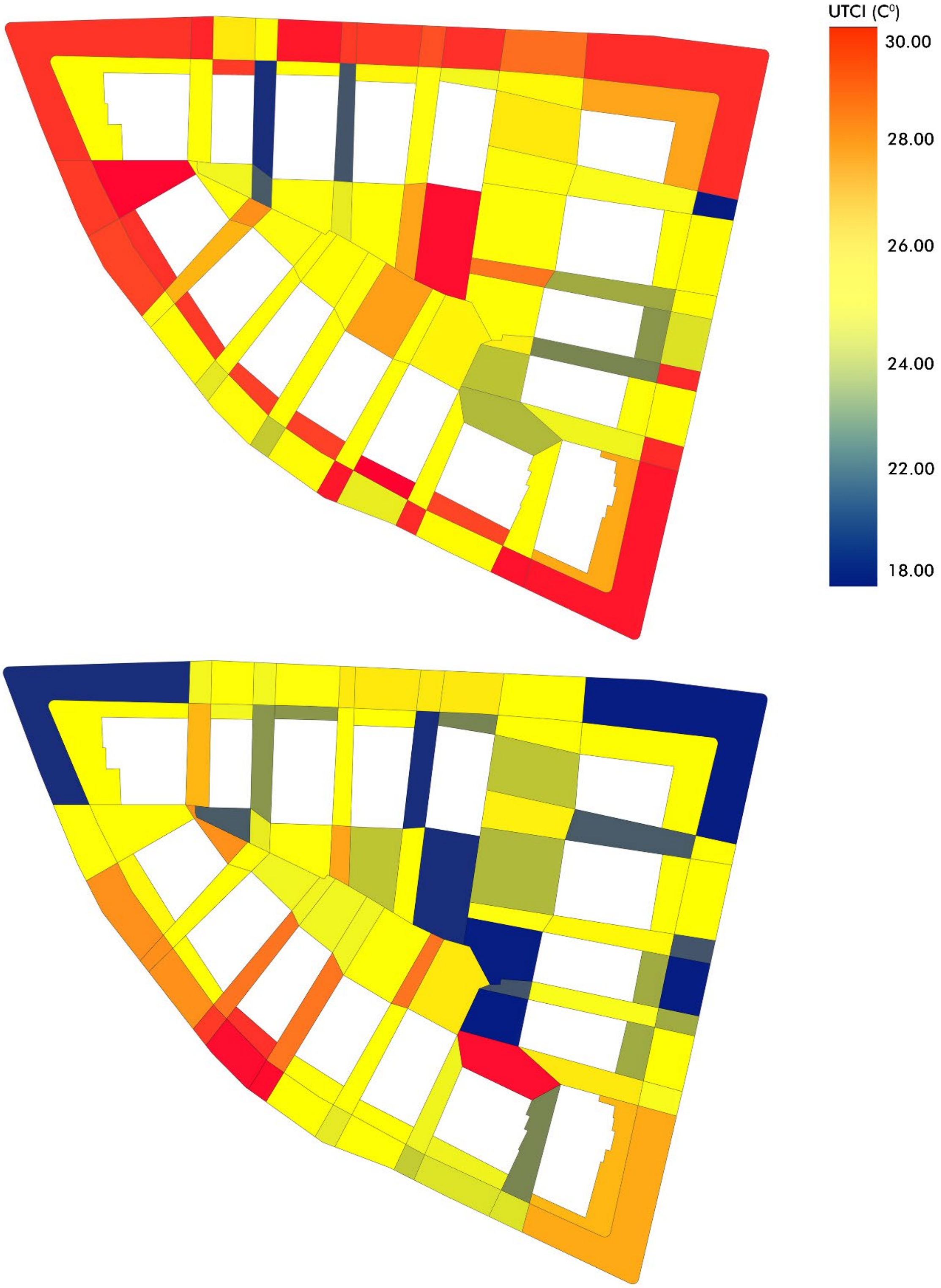

Figure 75. UTCI Patch comparison

5.4 Discussions

The aim for creating a approach that designers and decision makers may follow for water conscious environment fed with greenery is exemplified in this research with a approach explained in detail and a case study that focuses on one of the biggest cities of Turkey with high impervious rate throughout the city.

The approach is supposed to be followed by people interested in developing consciousness in their future perspectives for cities. Although the approach requires the knowledge or experience of similar tools, there is no need to be an expert about any of these tools. Even decision makers can apply the approach to small areas manually by following the process. For these people who may not calculate or foresee the results of their choices, the study area has been an example of how their choices may create environmental impacts on the area. These impacts may either be positive or negative depending on the proposals. Therefore, a background for the water management and their tools should be developed before starting such a case.

The study contributes to the existing literature by focusing on the gap on street-scale and integrating computational methods to a design approach. Although street-scale interventions already exist within nature-based solutions, there have been any developed design approach for integrating these tools to built environment. Moreover, environmental simulations enable a systematic approach and adaptability to various scales and conditions. Therefore, the study is an valuable asset for different stakeholders you want to develop a water-sensitive urban environment at street-scale.

Qualitative Changes at Environmental Conditions

The runoff comparison is made over two different states. First state is the runoff comparison of existing and proposed conditions which can be seen in Figure 68. Comparison of runoff amounts. This comparison is mainly based on different type of surfaces which treat water in a directed manner.

The proposed scheme did not only improve the runoff condition of the area but also opened a room for the possible worsening scenarios in the future by exceeding the capacity of the runoff amount 27 times compared to existing situation from 571 m^3 to 15.966 m^3. Total surface that can treat water for possible situations increased from 4487 m^2 to 19160 m^2. Where the maximum amount of rain recorded in the area is 89mm, the proposed scheme can withhold to four times of that amount in the upcoming years where the extreme weather occasions are expected to increase.

It is also possible to compare the two states over the patches which are supposed to be guiding the treatment sorting process. Figure 69. Runoff analysis projected onto the patches for comparison. shows the comparison of runoff coefficient of patches. This figure shows that almost all the patches are improved their runoff performance compared to previous condition.

The qualitative analysis clearly shows that nature-based treatments for water management decreases the runoff amount to cope with problems related to. Other than qualitative evidence, it is also expected for the designed environment to help managing water by secondary effects of having greenery in the city context.

Like runoff amount, there are drastic improvements with outdoor thermal comfort in proposed scheme. The biggest changes happened at the corners of the site which was also aimed at the beginning of the revaluation of treatments. The changes made for improved outdoor thermal comfort for social integration and well-being is visible in previous figures. Other than that, overall temperature of the site is reduced from 27.61 to 24.37. Moreover, the number of patches with discomfort decreases from thirty to thirteen while the comfortable patch amount is increases from nine to eighteen as can be seen from Figure 74. UTCI Patch comparison.

The case study shows that the nature-based water management tools greatly help to deal with environmental problems that our cities face today like water scarcity and urban heat island. Therefore, integration of these tools to not only to our cities in neighbour scale but also other scales can be priority for the upcoming generations.

Stakeholder Participation

The proposed design approach can be furthered with different stakeholders of the city. Policymakers may use the approach to create maps of proposed treatments along with researchers and designers to inform and encourage landowners to reconsider the built environment. Similarly, local people or NGO may demand the proposed methods to be applied to the public areas by governments or municipalities.

The proposed design approach enables the tools to be considered at larger scales. Therefore, municipalities can thoroughly investigate the needs of their territories and call the practitioners to contribute and different stakeholders of the city such as local people, visitors, investors may be called upon too.

Improved well-being

The research method with qualitative and quantitative methods should be also discussed from both aspects. Qualitative aspects of the proposal explain itself through the data visualizations. In that manner, the approach and the followed design method help fighting with increased rainwater runoff in rapidly and unconsciously developed cities like Ankara. Moreover, this method improved the outdoor thermal comfort of the selected area respectively while contributing to the social development of the area by creating areas where people can spend time comfortably.

Figure 76. Comparison of proposed and existing. A) Existing, B) Proposed.

On the other hand, the proposed scheme is designed together with the built environment within the light of design principles explained in 5.2.7 to create an integrated environment for the habitants. The integrated environment is not only supposed the increase the efficiency of the projected water management and thermal comfort performance, but also support the habitants of the area to use the public spaces actively for different purposes or create a joyful environment for the visitors of the site. In both cases, the social and non-simulated benefits of the treatments like improved air quality, reduced noise, increased biodiversity should be considered as an important aspect of the approach.

Scalability

The study includes parameters that are no specific to any scale and site. Patching system and simulations can be applied to any scale. Therefore, although the project site is selected as a building island in a city, the site could have been selected as the whole city. However, that selection may require additional scenarios for different surfaces. Other than that, the whole approach can be scaled and adjusted for different sites. Different climatic conditions must have been considered only if there’s a major change in the location of the site such as different city or parts of the city.

CHAPTER 6

CONCLUSION

The scope of the thesis includes but not limited to water management in built environments, street-scale water management treatments, outdoor thermal comfort and nature-based solutions. Within the scope, a approach towards an nature-based water management strategies integrated built environments is investigated, formed and tried on a study area in Ankara, Turkey. The development and application of a design approach for water management investigated and the results revealed the following conclusions:

- It is hard to imagine an ecosystem where there's no awareness about water and all the living beings. The relationship between the built environment and its environmental consequences which effects everything inside of it should be thoroughly investigated and necessary actions should be developed and taken.
- Although the buildings consume enormous energies and emit disturbing amounts of carbon dioxide to atmosphere, the outsides of the buildings are important playgrounds for the designers to play around and develop beneficial strategies.
- Application of the determined tools are important part of development of environmental strategies. Therefore, a approach should include possible directions for future implementations and possibilities. This option should be carefully integrated to design scheme.

- Due to the complex nature of cities, a unique approach should be developed for different areas. It is not an effective and suitable way of applying the approach everywhere with the same design principles. Therefore, each site should be carefully investigated by designers, individuals or groups.
- Environmental simulations are beneficial tools to understand the effects of our choices or just simply the existing situation. However, these tools should be supported with qualitative data to reach more accurate goals in the future.

To conclude, water is an important subject on the table and the threat is real and closing. To act in time, every discipline should play their part to contribute for a sustainable future. Architectural agendas should include the environmental concerns of the day and develop strategies accordingly. This research is a part of that development.

6.1 Limitations of the Research

Due to its intricate way of working back and forth with qualitative and quantitative methods, the thesis focuses limited inputs. Although the input types vary like weather data, water management tools, nature-based solutions and environmental simulation methods, the choice in each of these groups are limited to their basic and most important examples. Even though there are many water management treatments, only the most effective and widely used methods are selected for the study. With a greater scope or scale, target-specific treatments should be added to the list.

Even though there are many complex-built environments with rich surroundings, the case study and its surface area are limited to a one building island in order to design in detail to create the most accurate example. Different environment would not require different water management methods, but also different analysis to understand the site. Therefore, the role of the designer can be important compared to selected area.

During the pandemic, the limited engagement with the site resulted in having a limited knowledge about the social condition or the active users of the site. Therefore, the users could not become an input for the development of the design scheme.

Software Limitation

Due to financial reasons, ENVI-MET's lite version is used to calculate the outdoor thermal comfort of the area. Since the lite of version of ENVI-MET limits the maximum dimensions of the calculation area, the resolution of the simulation led the lost in the detail of small interventions for the site. Moreover, the limited material library of the ENVI-MET, affected the accuracy of the performance.

6.2 Further Studies

Architectural programs may enrich the development and integration of nature-based solutions to habitant's lives. Although integration of the program would require a detailed understanding of the site and, so increase in dedicated time and willingness, the programs would contribute to the social and economic sustainability of the areas in future. Therefore, not only designing for environment but also for the habitants would help to build a more resilient future for our cities.

The proposed framework can be prepared in detail for different scenarios and extended to fewer complex parts of the cities by preserving the notion of small, easily applicable and natural interventions. Although this research focuses on street-scale interventions, designers may focus on human scale to ensure that people can spend quality time at outdoors. That would lead not only increased well-being at the cities but also contribute to national economy in various ways.

The proposed analysis method can be expanded to include the secondary effects of NBS which is an important tool to fight with air pollution, loss of biodiversity and noise pollution. Qualitative data of the selected treatments effect on environment would be an important input for the designers while approaching to the case.

Surrounding Area

Lack of surrounding area in the 3D model affects the outcome in simulations and calculations. To achieve a higher resolution and more accurate results, the surrounding can be modelled in detail and larger scale and encompass the working area. However, in the study's case, the limitations in the simulation tool also affected the scale and detail of the model. The inaccuracy is neglected in the study since the main aim of the study was to show how to develop a design approach. Therefore, in the later studies, stakeholders should consider performing the environmental simulations with a more detailed and larger 3D model to achieve more accurate results. Moreover, it should have been taken into consideration that this approach would require more time and labour during the process.

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