MASTER THESIS

Ecosystem Services and Green Infrastructure in Cities

By

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Abstract

With the general acceptance that climate change is happening and urban areas are expanding, the green lands are under pressure and the abundance of vegetation is under threat worldwide. The awareness of this reality and its potential effects is increasing as the occurrence of extreme weather events. Climate change in the Netherlands has unfavourable effects such as flooding due to peak rainfall, more frequent and severe droughts in several parts of the country. In order to adapt to urban climate change, improving water resource management has become a necessity. Green infrastructure can be seen as a potential solution for water resource management and it also provides opportunities to recuperate green space and built-up ecosystems in the urban environment. The objective of this thesis is to evaluate four green infrastructure methods (green roof, roof garden, polder roof, and roof park) used by the company "De Dakdokters" in adapting to urban climate change in the Netherlands. Through the analysis and comparison of ecological, economic and socio-cultural benefits offered by each method, recommendations for further enhancing their impacts have been provided.

The research data was gathered by conducting interviews with experts from different universities and with company representatives and by examining relevant documents. Several benefits of the methods were identified, such as rainwater buffer, air purification, reduced ambient temperature, increased longevity of roofs, reduced energy consumption, and improved urban biodiversity, social cohesion, and healthy environment. The range of benefits for each green infrastructure method was also identified and presented. Furthermore, the strengths and weaknesses of each green infrastructure were described and compared based on the assessment of the benefits.

Finally, recommendations were proposed to improve the green infrastructure of De Dakdokters for adapting to urban climate change. These are: 1) Extensive roofing with growing media over at least 75% of the roof footprint of the building. 2) The roofing system should have maximum runoff coefficient. 3) Existing building analysis must be conducted to determine the structural load limitation. 4) Having more research that learns from miscalculations in roof design, to avoid error repetition in future roofs. 5) Propagating and testing the roof potentials could develop robust green infrastructure plant communities.

Keywords: climate change, urban population, green infrastructure, ecosystem services, green roofs.

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Chapter 1 Introduction

1.1 Background

Climate change has various impacts all around the world, such as increased levels of precipitation and rising temperatures, which cause urban flooding, drought and heat stress. The initial response to the climate change problem focused on 'mitigation' i.e., reducing the emission of greenhouse gases to minimize the predicted harmful consequences. However, as time passed by, the experts, as well as the research community, also took into account adapting to inevitable consequences. Urban areas are vulnerable to the effects of climate change. Particularly dense areas, streets, and buildings retain heat, causing the urban heat effect. This can cause health problems and reduce worker productivity, while energy demand rises to cool buildings (Roders et al., 2013). Moreover, sewage infrastructure is often unable to process increasing quantities of precipitation, leading to urban flooding.

Living in the Netherlands, people are indistinguishably associated with water, regardless of whether they live below sea level or near a water stream prone to flood, there will always be a challenge for water safety. On top of these challenges, there is climate change, increasing the amount of precipitation with 5% by 2030 and the intensity of this precipitation (KNMI, 2014). Together with sea-level rise, this poses new threats to the country and its inhabitants. One of the best-known measures in the country against the sea and river flooding are the dykes or the room for the river projects. Another measure which is in The Netherlands relatively unknown is green infrastructures, although green infrastructures represent a distinct type of urban habitat, they have been treated largely as an engineering or horticultural challenge, rather than as ecological systems. The environmental benefits provided by green infrastructures derive from their functioning as ecosystems.

Green infrastructure can be constructed on the flat roof of buildings, varying from houses, offices, living boats, and garages, and is partially or totally covered with vegetation (Bell et al., 2013). Besides this horizontal green infrastructure, vertical green "roofs" are also possible on the outside walls of buildings. There are two types of green infrastructures: extensive and intensive. The extensive green infrastructures are relatively shallow, simpler and lighter weight option since lighter weight option they do not need extra structural support most of the time. Intensive green infrastructures, on the other hand, are thicker, heavier and can have a wide variety of plants, making the roof looking more or less like a regular garden or park (Bell et al., 2013). These rooftop gardens/parks need the same amount of maintenance as regular gardens and parks, which is more than required for extensive green infrastructures (Ebbink et al., 2009). Since this construction is heavier it also needs more structural support than an extensive green infrastructure (Ebbink et al., 2009).

Green infrastructures are a perfect opportunity for urban areas, which often have a limited number of permeable surfaces, and therefore, the rainwater is not able to infiltrate and runs off over the streets, as the amounts of precipitation will also become too high for sewer systems. The green infrastructures will increase the capacity for water storage and delay the drainage of the precipitation to the sewer system (Ebbink et al., 2009). Some other positive effects of green infrastructures are insulation, a natural way of cooling houses, which can lower energy bills. Green infrastructures also provide aesthetic value and increase the wellbeing of people (Bell et al., 2013). Furthermore, by mitigating urban heat islands, green infrastructures provide shade and remove heat from the air through evapotranspiration (Bell et al., 2013).

De Dakdokters is a social enterprise, becoming an example of a sustainable company in the field of roofs in the Netherlands. Since 2010, De Dakdokters, improving urban health by transforming grey roofs into more useful green roofs. The different roofing methods of the company are green roof, roof-park, roof garden, polder roof, and roof renovation They see rooftops as something more than unusable covers to houses; sustainable drivers for our urban future. They transform those un-utilized roofs into places for nature development, recreation, water storage and food and energy production (De Dakdokters, 2017).

1.2 Problem Statement

As natural land keeps on being replaced with impervious surfaces because of population growth and urbanization, the need to recuperate green space is becoming increasingly critical to maintain environmental quality. On top of these challenges, there is climate change, increasing the amount of precipitation in cities which causes flooding and heat island effect (during the nocturnal hours there is an average higher temperature in an urban area than in the surrounding areas) as the negative effect of climate change on urbanization. Installing green infrastructure is one option that can reduce these negative effects while providing various environmental, economic, and social benefits. In the effort to adapt water management to climate change, many cities in the Netherlands have used different methods of green infrastructure roofs. Green infrastructures have been shown to retain 60-100% of the stormwater they receive, a major benefit being ability of absorbing and slow release of stormwater over a duration of several hours. This new trend of green infrastructure is promoted by the Dutch government, whereas only three main companies (Dutch Green Roof, Zinco, De Dakdokters) are currently offering the services. De Dakdokters is a relatively new company in a field, it offers five types of sustainable roofing. Due to little knowledge with regards to their products' ecosystem services facilitation to urban climate change adaptation, it contributes to a slow up-take in the market. The thesis will investigate the current status of and the potential improvement opportunities for the green infrastructure methods of De Dakdokters. This will contribute to reducing the knowledge gap related to economic and ecosystem services provided by different green infrastructure methods with regards to adapting to urban climate change.

1.3 Research Objective

The objective of the thesis is to evaluate the possible impact and improvement of green infrastructure methods of the company 'De Dakdokters' in adapting to urban climate change in the Netherlands.

1.4 Research Questions

The main research question is formulated as follows:

How can the contribution of green infrastructure methods of De Dakdokters to urban climate change adaptation in the Netherlands be improved?

The following three sub-research questions were formulated to be able to answer the main research question:

1. What are the features of the green infrastructure methods of De Dakdokters?

2. What are the ecosystem services that the green infrastructure methods of De Dakdokters offer enabling to adapt to climate change in urban areas from the perspective of ecological, economic and socio-cultural values they offer?

3. What are the strengths and weaknesses of the green infrastructure methods of De Dakdokters?

Sub-question 1 helps in understanding the four methods under study: green roof, roof garden, polder roof, and roof park. These four methods were chosen because their ecosystem services appear to be more prominent to bring about adaption to the urban climate change. On the other hand, the fifth roofing method called roof renovation only provides waterproofing using natural material hence not addressing urban climate change adaptation. Meanwhile, sub-question 2 provides the impacts of the respective roof based on the ecosystem services they deliver that enable adaptation to climate change. Lastly, the sub-question 3 identifies the strengths and weaknesses of each roofing method, which helps in making recommendations for potential improvement opportunities.

Chapter 2 Literature Review

In this chapter, relevant works of literature for the research are described. First, section 2.1 describes the urban climate change in general. Section 2.2 describes the ecosystem services and their types. Section 2.3 describes the urban green-grey infrastructure and its benefits and drawbacks. Section 2.4 describes the criteria of evaluation for green infrastructure which are selected from the above literature reviewed.

2.1 Urban Climate Change

Understanding the risks and impacts of anthropogenic climate change remains one of the most societally important and pressing challenges (National Academies of Sciences, Engineering, and Medicine, 2018). Whilst heat-waves (periods of prolonged high temperatures) and heat stress have played a role in population dynamics for centuries (Carleton et al., 2017). Recent studies show that climate change will expose an increasing number of people to extreme heat (Hondula et al., 2015). Due to the on-going climatic changes, Europe is foreseen to face difficulties so as to adapt and mitigate the consequences of severe weather conditions. Apart from the extreme heat, there is a foreseen increase in some extreme natural events such as floods, drought, and wildfires. Different parts of Europe will be subjected to different climate hazards, with some areas experiencing more than one climate hazards as seen in Figure 1 (Emilsson & Sang, 2017). The current European development trends are characterized by continuous urbanization process, in the midst of climate change. It is foreseen by 2050 more than 66% of the world population will be situated in urban areas, therefore climate change impacts might be experienced to a greater degree in urban areas in-comparison with its encompassing landscape. Due to the difference in urban and rural areas, they tend to have different weather conditions. Whereby the urban weather is more polluted, less rain and wind, colder, and much warmer (Emilsson & Sang, 2017).

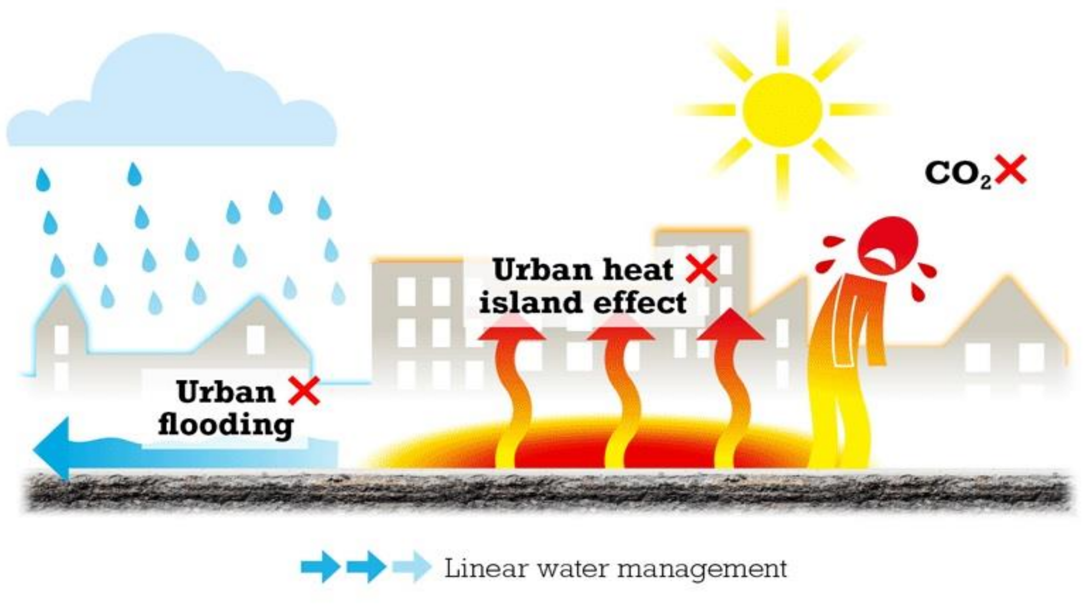

Figure 1 Effects of urban climate change *Source: https://f.jwwb.nl/public/p/b/h/temp-zttxzqfjzuqtcxkjvznx/pvcurrentcitycycle.gif*

2.1.1 Effect on urban temperature

The urbanization process has many challenges one among them is Urban Heat Islands (UHI) effect. The effect is seen as an increase in urban temperature, which when coupled with climate change impacts further enhances the effects experienced. Three parameters of urbanization directly increase the UHI, these are: (1) increasing amount of dark surfaces such as asphalt and roofing material (2) decreasing vegetation surfaces and open porous surfaces, for instance, rock or soil that increase concealing and evapotranspiration, and (3) heat created through human movement, for instance from vehicles and air-condition (Emilsson & Sang, 2017). As the above parameters are not equally distributed, consequently the UHI effect does differ across the city. The effects are more pronounced in areas with more factors such as highly developed lands in-comparison to suburbs (Emilsson & Sang, 2017).

2.1.2 Effect on urban hydrology

The frequency and duration of occurrence of coastal and inland flooding are expected to double in Europe by the year 2045 due to a number an array of factors. These factors are the rise of ocean and sea level, increase in storm frequency, decrease in drainage due to increase of impermeable surfaces due to development works such as tarmac roads and many more (Emilsson & Sang, 2017). Impermeable surfaces alter the infiltration capacity which when at a large-scale lead to large amount of waterlogging in the urban area. Furthermore, some of the urban areas are situated in flood plains or along the coastal area which is very vulnerable to floods. Coupled with climate change impacts, the coastal and inland flooding are expected to be experienced to more, especially in urban areas where there is highest level of development.

2.1.3 Effect on urban habitats and biodiversity

Global climate change influences several factors that are important for urban habitats and biodiversity. Several preservation approaches emphasize relict habitats and native species in urban settings, a paradigm shift towards considering the whole range of urban ecosystems (Kowarik, 2011). The changes in temperatures, rainfall patterns, extreme events, and increased carbon dioxide concentrations can influence the factors associated with single species, population dynamics, species distribution patterns, species interactions, and system services (Emilsson & Sang, 2017). Increasing urban temperatures and altered precipitation dynamics can influence species community development by limiting water availability throughout the growing season and changing the nutrient dynamics.

2.2 Ecosystem Services

Within the ecosystem, human existence in a dynamic relationship with their surroundings. Ecology plays a significant role in understanding the benefits humans attain from the ecosystem. Through understanding these benefits and interactions, the human may develop markets for system services, environmentally friendly technologies and make decision considering its environmental impacts (Carpenter & Folke, 2006). The benefits and services offered by the surrounding environment are called ecosystem services.

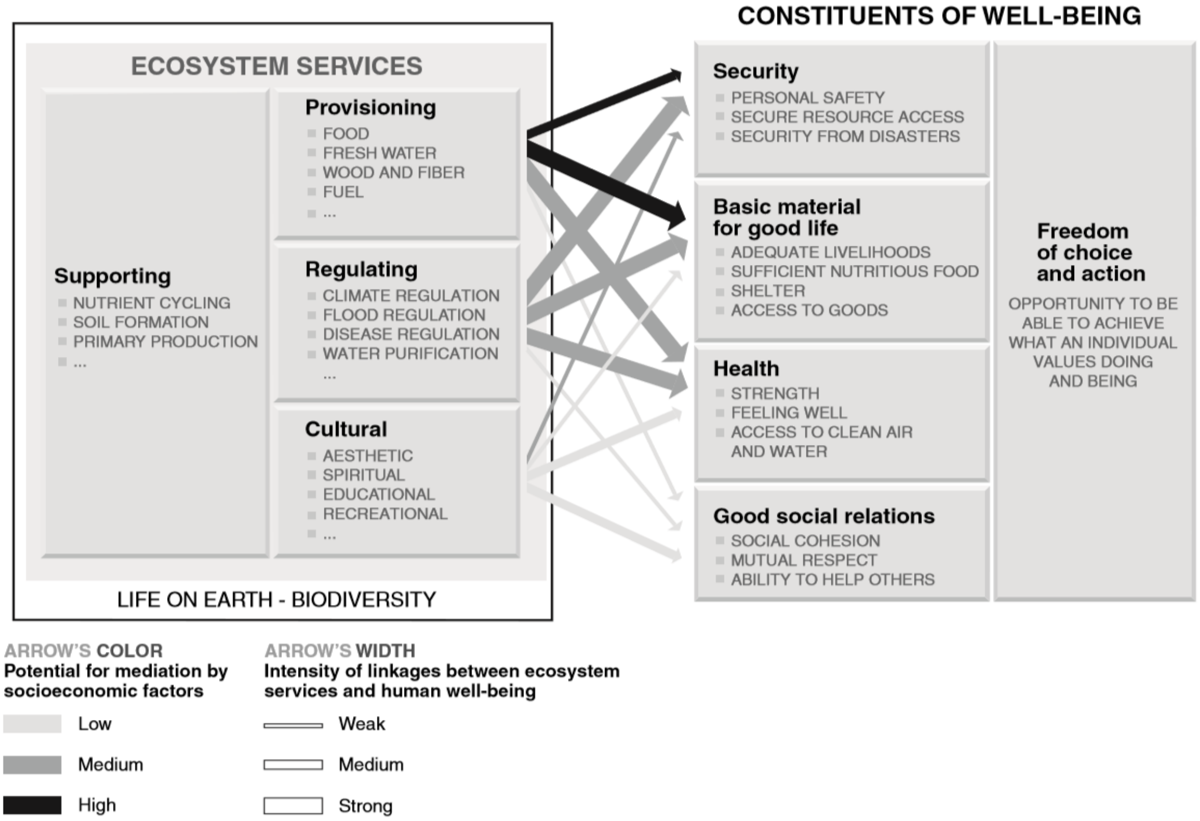

Figure 2 Linkages between ecosystem services and human well-being *Source: Millennium Ecosystem Assessment (2005)*

Ecosystem services contribute to human well-being directly by providing food, water, etc. and indirectly by pollination of plants, nutrient cycle, etc. These indirect services of the ecosystem are crucial for the self-sustaining of the ecosystem and have different spatial scales (Bolund & Hunhammar, 1999). Human activities in the last 50 years have severely degraded the ecosystems and hence the services they provided (Millennium Ecosystem Assessment, 2005). This degradation is brought by a number of driving factors that affect directly or indirectly. The factors are referred to as drives as they promote occurrence of ecosystem degradation that translates to degradation or decrease of ecosystem services (Anonymous, 2019). The indirect drivers do not have an effect directly on ecosystem, but rather influence or magnify the direct drivers' effects. Examples of indirect drivers include population growth, change in economic activities, and socio-political factors. Direct drivers such as deforestation, overgrazing, irrigation, use of pesticides, affect the ecosystem directly. These drivers alone might appear insignificant but when coupled with coupled together have great effects. The degradation of ecosystems is a complex phenomenon that is spatial and temporal dependent. The ecosystem services can be categorized into four groups, namely supporting, provisional, cultural and regulating services, as shown in Figure 2 and presented below. The supporting services such as production of clean air, clean water and primary production, have an auxiliary role in sustaining other the ecosystem services.

2.2.1 Provisioning ecosystem services

These are the services which provide benefits that human beings acquire from the ecosystem in the form of different products such as marine products, forest products, energy, natural remedies, water, genetic resources etc (Bolund & Hunhammar, 1999). Principally, provisioning ecosystem services comes under direct services through providing various products as mentioned above (Jarrin et al., 2019). The provisioning services play a vital role in human survival through being consumed on a daily basis at household level and their role in the economy. Majority of the services are being traded both at local and international market, example of these trades are timber trade and mineral trades (Scholes & Smart, 2013). Preventing climate change and improving the quality and quantity of water cycle can be done by optimizing provisioning services, this benefits the water resource management.

2.2.2 Regulating ecosystem services

Regulating ecosystem services are often considered to have indirect benefits to human well-being with most of them not physically observed and delivered mainly through a range of different co-production processes (Palomo et al, 2016). The interaction of ecosystem processes (co-production process) results in a mechanism that enable it to regulate local microclimate and the combination of these mechanisms establish a grander scheme that covers national and even global climate conditions (Bolund & Hunhammar, 1999). A good example of these process is how trees, wetlands, and different soil formation found in nature, soak up, retain and control water flow that translates to flood control, river levels control and water availability. Another example is water regulation is achieved from co-production process utilizing various irrigation ditches. Likewise, the cooling effect of trees and their ability to absorb and store carbon facilitates regulation of gases in atmosphere (Jarrin et al., 2019, Liekens et al., 2013). Through this and another similar process, natural environment can regulate air circulation, water flow, local temperature, nutrient circulation, climate and many more.

2.2.3 Cultural ecosystem services

There are multiple different definitions for the cultural ecosystem, with debates on utilizing the word "services" as it infers a financial gain. It is generally agreed that the cultural ecosystem cannot be assessed by using discrete quantifiable units, as its value depends on the concerned individual and community views and practices (Dickinson & Hobbs, 2017). This makes it a complex multifaced terminology which is made up of people way of life, identity or certain social process. Cultural ecosystem services are nonmaterial benefits which are offered from nature (Kirchhoff, 2019). These nonmaterial benefits include spiritual enrichment, cultural symbolism, aesthetic experiences and recreation. The cultural ecosystem services differ from other ecosystem services, as they provide nonmaterial benefits and require a certain degree of human interaction. For example, a forest provides air quality control and carbon sequestration regardless of human intervention, but for the same forest to have symbolic or recreational purpose a human interaction is needed. Therefore, assessing and quantifying of cultural ecosystem services has been more challenging, nonetheless a rewarding endeavor due to their role in human well-being (Jarrin et al., 2019). This role can provide feelings of belongingness, relaxation, spiritual enrichment, personal and community identity, emotional control and many more that are beneficial to the well-being of humans.

For the purpose of this research, the ecosystem services from green infrastructure were analyzed from the perspective of benefits offered that enable adaption to urban climate change. The benefits were categorized into three categories, namely economic, ecological and socio-cultural. The ecological and economic benefits are derived from provisional and regulating ecosystem services and socio-cultural benefits derived from cultural ecosystem services.

2.2.4 Resilience of ecosystem services

Resilience is defined as the ability of a system to renew and sustain its condition or processes in spite of the external disturbance (Carpenter & Folke, 2006). In the domain of ecosystems, resilience is often related to slowly-changing biogeochemical pools, biodiversity or long-lived organism. The ecological basis of resilience and its connections to ecosystem services is not fully understood yet. The existing knowledge suggests the persistence existence functional group of species in an ecosystem contributes to its performance and services it generates (Hooper et al., 2005). From the interaction of within the functional group of species and the overarching landscape or seascape, creates sources of renewal and re-organization of the system in response to changes or influences. From left to right in Figure 3 is: a) Grazing fish facilitate keep the substrate accessible for coral recruits; b) fertilization by insects supports food production and cultural services of terrestrial ecosystems; c) seed spreading by mobile link species, like monkeys, facilitates ecosystem reorganization following disturbance. The MA created a crucial contribution by distinctively identifying ecosystem services that regulate climate, floods, diseases, water and air quality, and so on. However, it failed to show connections of the identified these regulating ecosystem services with resilience. Nevertheless, it acknowledges the feature of the ecosystem in a complex way to affect the overall resilience of the ecosystem present.

Figure 3 Ecosystem services *source: Carpenter & Folke, 2006*

2.3 Urban Green Infrastructure

Infrastructure systems are directly connected to the urban form and their presence frequently determines the existence and location of modern settlements, both in developed and developing countries (Seto et al., 2014). Infrastructure is the backbone of the urban centre which facilitates nearly all of its activities. It affects, directly and indirectly, both humans and ecosystems. A good example of these infrastructures are roads, bridges, communication towers, power stations and many more. With increasing urbanization, development and population growth, the demand for infrastructures has increased (Davis, Caldeira, & Matthews, 2010). Most of the urban infrastructures utilize energy in their operations which is accompanied by greenhouse emissions. Greenhouse emissions such as carbon dioxide and chloroform carbons have been associated with global warming and climate change. Due to this the sustainability of the infrastructures has been a major concern in most urban areas and cities. Methods of attaining more ‘environmentally friendly’ infrastructure are an imperative topic of research as well as policy guidelines. One among the areas of interest being considered is ‘green infrastructure’ (Norton et al., 2015). Due to the developmental activates most of the natural infrastructure (for example vegetations, rivers, plains, shorelines) has been altered or eliminated. In cases where their natural infrastructure is in the way, the technical solution is created to handle them, for example, is clearing of forest, diverging of rivers streams and piping of creeks. As a result, most of the developed urban areas are lacking or have reduced natural infrastructures within the given ecosystem. These activities alone do not have much impact, but when aggregated together they have great impact as the services offered by the natural infrastructure decrease. A good example of changes in land drainage capacity, air quality, wind circulation, reduction in ambient temperature and so on. As a result most of the urban areas are lacking natural infrastructures like vegetations (Merriam, 2010)

Green infrastructure is a great example of collaborative land management that addresses both developmental needs and conservation of natural infrastructures. It addresses simultaneously both infrastructural requirements and improves ecosystems which result in the gaining of ecosystem services such as air purification, stormwater management, erosion protection and mitigation of urban heat islands. Improving the health of ecosystem offers a cost-effective alternative option to traditional 'grey' infrastructure, in-conjunction it offers advantages in the form of ecosystem services that benefit humans and biodiversity (European Commission, 2016). Other benefits of green infrastructures are it creates a green economy, job opportunities and enhances biodiversity. A wide range of ecosystem services is delivered by green infrastructures as they are strategically planned in a network of natural and semi-natural areas with other environmental features. The health and quality of life of citizens are improved by the network of green and blue spaces in urban areas. Green infrastructure planning is an effectively proven tool to deliver economic, ecological, and socio-cultural benefits through natural solutions and help minimize the dependence on 'grey' infrastructure that is often costly to build and maintain (European Commission, 2016). An example of green infrastructure is given in Figure 4.

Figure 4 Green roof *source: https://greeninfrastructureontario.org/app/uploads/2016/10/Green_Roof_Hero_Final.jp*

2.3.1 Grey vs green infrastructure

Grey infrastructures are an important part of today's urban cities and societies and have been integrated into most of their daily life and activate. Though they are important, most of them are not sustainable as they are energy-intensive and produce un-environmentally by-products such as construction wastes (Müller et al., 2013). The energy requirement of grey infrastructure is mostly in electricity and heating of building which is mainly associated with greenhouse emissions. The emissions initially occur during the construction phase, during its operations and lastly a lesser extent at the end of its life. It was observed that transboundary (outside of city boundaries) infrastructures that are used within a city tend to have higher greenhouse emission levels which contribute to overall grey infrastructure emissions. The policymakers, scholars, and environmentalists have acknowledged the importance of addressing the negative environmental effects of grey infrastructures (Müller et al., 2013). Various solutions are aimed to mitigate climate change and adaptation to this kind of phenomenon is drafted, with one of them being green infrastructures.

Green infrastructures are a fusion of man-made green spaces and natural ecosystems that utilize natural energy sources for the purpose of providing infrastructural services and safeguarding the biodiversity of both rural and urban areas. It consists of technological practices coupled with the implementation of green spaces into urban areas. Examples include urban forestry, green and blue roofs, wetlands, rain gardens, and parks. In addition, green infrastructure "encompasses a wide variety of natural and restored native ecosystems and landscape features that make up a system of 'hubs' and 'links." (Benedict & Mcmahon, 2002). They are mostly located outside of urban boundaries but are incorporated in cities at a high degree. Links are "the connections that tie the system together and enable green infrastructure networks to work."(Benedict & Mcmahon, 2002) They include greenways, conservation corridors, and green belts as natural lands serving as biological conducts for protecting wildlife and biodiversity. Hubs protect green networks as they offer a destination for ecological process to pass through and protect wildlife. Few examples of hubs are urban green space, community parks and national parks which are largely protected and reserved areas (Benedict & Mcmahon, 2002). Green infrastructure envisioned to work on different ranges of scales, micro-scale on private property and macro-scale on centralized public projects. This scale range connects the urban and rural areas together. Green infrastructure offers the additional advantage of socio-cultural benefit apart from providing society a safer way of dealing with climate change and the feeling of fortification for low economic costs.

2.3.2 Green infrastructure and a healthy urban living

Social benefits derived from green infrastructures are dependents on the concerned community where it is implemented, their cultural value, aesthetic, the background of the user and method of using the green space. It contributes to bringing social interaction, establishing a meeting point, and promote cohesion by giving a sense of place (James et al., 2009). A range of recreational and physiological benefits, opportunity for community bonding and education for adapting to climate change are provided by urban ecosystem. The psychological benefits are derived from citizen contact with nature which is found to reduce stress, criminal activates, anti-social behavior and restore attention. In addition to affecting self-regulation, increase enjoyment, restorative experiences and aesthetic appreciation on nature. It also encourages exercise and doing physical activates like jogging and cycling that bring about relaxation, improved physical state, comfort, and satisfaction. This reduces the risk of obesity, diabetes, heart problems and other health effects accompanied by stress and lack of exercise. Apart from the above, it also contributes to air purification that improves air quality, water purification and has a cooling effect that is all beneficial to human well beings and ecosystem.

Commonly agreed that green infrastructure offers benefits to the natural environment, they protect them as well as improvise their 'health' (Tzoulas et al., 2007). The increase in vegetation cover that assists in biological diversity conservation, maintain coherence of ecosystem and offer a base for ecological network formation that prevents dispersion of habitats and maintenance of overall sustainable landscape. It is observed that species-rich ecosystem has a better organization, maintenance and productivity in comparison to their counterparts with less diverse (Tzoulas et al., 2007). The ecosystem services and functions derived from green infrastructure are beneficial to both ecosystem and human health and well-being, therefore, enabling a healthy urban living

2.3.3 Green infrastructure in the Netherlands

Among green infrastructure green roofs are booming in the Netherlands. Many architects include green roofs in their designs, as project-developers and housing associations also see the benefits. The multiple uses of space are essential, especially where there is limited space, as it is the case with the Netherlands. However, benefits such as water retention, improved air quality, biodiversity and reduction of the UHI effect were not considered until recently (Kerssen, 2019). This mentality has modified, and research has been carried out, resulting in the awareness that green roofs benefit society in various ways. Water is a specifically vital problem in the Netherlands, as water management is an ongoing subject: "The Netherlands is a rustic that historically is related to water control. For survival, the Dutch had to be imaginative and advanced a surprisingly sophisticated manner to live with water'(Kerssen, 2019). Therefore, sustainable urban drainage and water retention are essential in how green roofs are introduced. Also considering the ecological benefits of green roofs, several municipalities, starting with Groningen, Amsterdam and Rotterdam, subsidize the installation of green roofs, (Kerssen, 2019).

The idea of blue and green roofs is being carried out in four areas of Amsterdam: Bellamy, Geuzenveld, Oosterpark, and Kattenburg (Licheva, 2018). These new roofs are capable of acquiring extra water under their plants. This will allow better protection houses and neighborhoods from the consequences of heavy showers, as well as warmth and drought. The blue-green roofs can take in a good deal extra water than the normal green roofs, in order that they can also evaporate moisture longer whilst it's hot and dry. The roofs incorporate sensors that allow them to maintain or release water according to the weather forecast. In addition, a greater variety of flora can be grown on blue-green roofs, which can improve the biodiversity of Amsterdam.

2.4 Criteria for the Evaluation of Green Infrastructure

From the analysis of literature on green infrastructure, ecosystem services, and urban climate change, the evaluation was based on the criteria of economic, ecological and social-cultural benefits they provide that enable adaptation towards urban climate change. The respective criteria of economic benefits are energy reduction, roof longevity, reduce stormwater, urban biodiversity, payback, and incentives. For ecological benefits the respective criteria include rainwater buffer, air purification, reducing ambient temperature and noise, urban biodiversity and erosion protection. Lastly, for socio-cultural benefits, the evaluation criteria were Social cohesion, healthy environment, and less vandalism.

Chapter 3 Research Design

3.1 Research Framework

The research framework is step by step activities to achieve the research objective, which consists of the seven following steps:

Step 1: Characterizing the objective of the research project

The objective of the study was to evaluate the possible impact and improvement of De Dakdokters green infrastructure methods in adapting to urban climate change in the Netherlands.

Step 2: Determining the research object

The research object in this research were the green infrastructure methods of De Dakdokters.

Step 3: Establishing the nature of the research perspective

This research was evaluation research. The different green infrastructure methods of De Dakdokters were evaluated based on their features and criteria of economic and ecosystem services they provide that enable adaptation towards urban climate change. From this evaluation, their strengths and weakness were identified, which acts as the base for comparison and recommendations. In this way, the impact and improvement of the roofs to adapt to urban climate change were identified.

Step 4: Determining the sources of the research perspective

To develop the framework, scientific literature on green infrastructure, ecosystem services, and urban climate change were used to gather data for the formulation of criteria for evaluating the possible impact and improvement of green infrastructure methods of De Dakdokters' in adapting the urban climate change in the Netherlands.

Step 5: Making a schematic presentation of the research framework

The research framework is described in Figure 5.

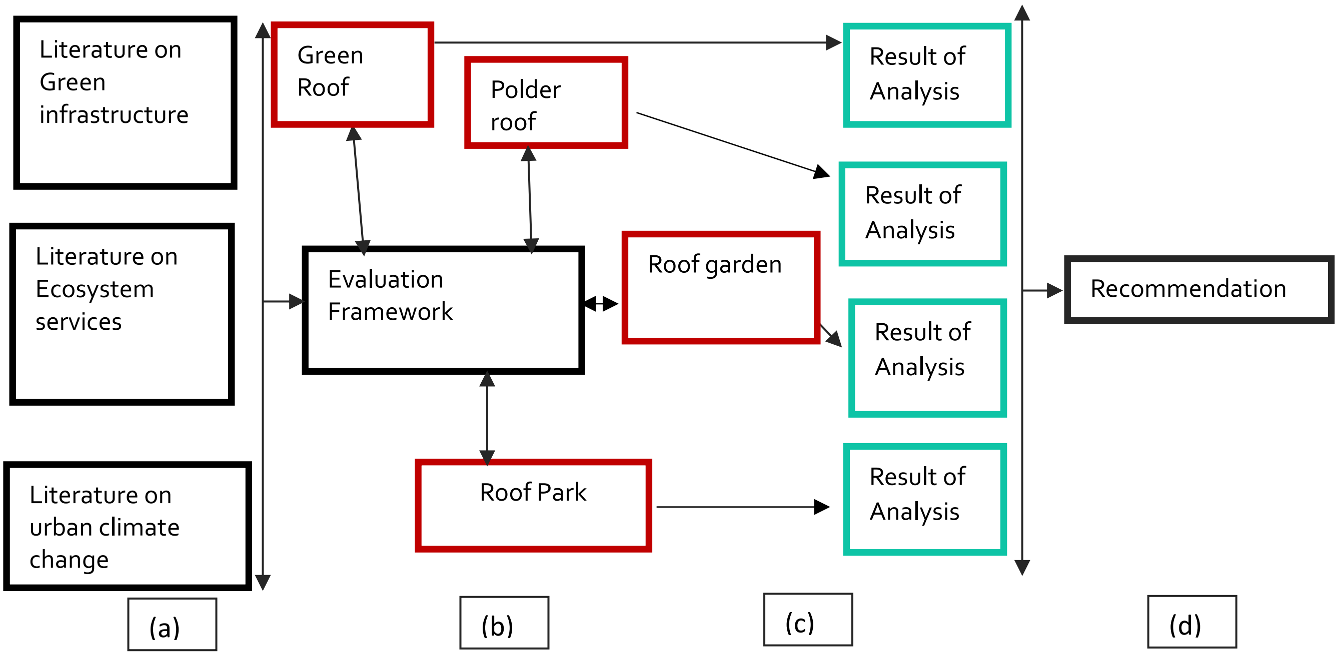

Figure 5 Research framework

Step 6: Formulating the research framework in the form of arguments which are elaborated

(a) A review of the literature on green infrastructure, ecosystem services, and urban climate change yield the evaluation criteria.
(b) By means of which the research object was analyzed to yield results
(c) Confronting the result of the analysis as the basis for the recommendation
(d) Recommendation on improving the roofing methods of De Dakdokters.

Step 7: Checking whether the framework requires any change

There was no need to change the framework.

3.2 Defining Concepts

For the purpose of this research, the following key concepts are defined:

Urban climate change: An increase in temperature causing discomfort, economic loss, migration and increased mortality rates on a global level.

Green Infrastructure: Strategically planned network with other environmental features to deliver ecosystem services

Ecosystem services: Are understood as different varieties of benefits that human kind derive from natural environment that have different values for example ecological value, socio-cultural values.

Ecological values: All factors that make up natural ecosystems provide to support native life forms from the green infrastructure

Socio-cultural values: Immaterial benefits such as spiritual and aesthetics from the green infrastructure

Economical values: Economic benefits from the green infrastructure

Location characteristics: This is understood to be the climatic conditions and geographic condition of the area which are the amount of rain, topography (high land vs low land), flooding frequency and urban heat island effect

Climate change adaptation: Adjustment of individuals, communities, organizations and natural systems in response to climate change, that reduces harm, facilitates recovery and enables exploitation of beneficial opportunities.

3.3 Research Strategy

The strategy used in this research was an evaluation of four green roofs of the company De Dakdokters. This strategy has been selected due to the presence of a small domain consisting of small number of research units and intensive data generation. The research was carried out in two stages, the first stage is evaluating the individual roofs, followed by the second stage of identifying strength and weakness of each roof for recommending improvements. In this evaluation, possible impact and improvement of green infrastructure methods of De Dakdokters in adapting to urban climate change in the Netherlands are identified.

3.3.1 Research unit

The unit of the research was the green infrastructure methods of De Dakdokters, Netherlands. It was purposely chosen because it is one of the leading companies in the field of sustainable green roof in the Netherlands. This company has five sustainable roofing methods out which this study focuses only on four types: green roof, roof garden, polder roof, and roof-park. These four types of green infrastructure are chosen because their ecosystem services appear to be more prominent to bring about adaption to the urban climate change.

3.3.2 Research boundaries

For this research, specific boundaries had to be defined to make sure it could be performed within the set time span. Because of this time limitation, four roofs of De Dakdokter are included in the study. Besides, each roof will be assessed based on the ecological, economic and socio-cultural values. The research doesn’t include the type of material used and type of plants that can be grown on each roof.

3.4 Data Collection

Data that was required to answer the research questions was collected through the examination of relevant scientific literature and practice documents, and by interviews with relevant stakeholders. The interviewees were two university experts and one representative from De Dakdokters. The professors were selected due to their relevant background and knowledge related to green infrastructure, meanwhile, the company representative offered knowledge on their green infrastructure methods. The first one was Dr.ir. Frans Van de Ven from TU Delft, a specialist in urban water management and Dr. K.R.D Lulofs from the University of Twente, specialist in water governance and planning. The company representative, Lisa Van Schagen, is a roof architect. The interviews with the university experts were focused on the negative effects and socio-cultural values of the green infrastructure. Whereas, interview with the company representative was focused on the economic and ecological benefits of the green infrastructure. The interviewees were initially contacted via mail, followed by interview via phone call or filling in the questionnaire as per their convenience. In Appendix I, the interview questions are found. Table 1 describes which material was required to answer each research question, what the source of the data was, and in which way this data was collected.

Research question	Information required to answer the question	Data source	Data collection method
1. What are the features of the green infrastructure methods of De Dakdokters?	Operating principle, structure, cost of installation and maintenance, the capacity of water and vegetation.	Secondary data: literature and documentation	Desktop research, mainly by internet search
2. What are the ecosystem services that the green infrastructure methods of De Dakdokters offer enabling to adapt to climate change in urban areas from the perspective of ecological, economic and socio-cultural values they offer?	Ecological benefits such as reduce noise and air pollution, sequester carbon, increase urban biodiversity by providing habitat for wildlife. Ecological benefits in relation to urban climate change	Secondary data: literature and documentation & Primary data from interviews	Desktop research, mainly by internet search Interviews (either face-to-face or via email)
	Economic benefits such as payback period by reducing the energy consumption		
	Socio-cultural value		
3. What are the strength and weaknesses of green infrastructure methods of De Dakdokters?	Features, ecosystem services and economic benefits of each roof	Secondary data: Literature and documentation	Desktop research, mainly by internet search

Table 1 Research materials and data collection

3.4.1 Research ethics

Ethical considerations were made as interviews were conducted during this research. Before contacting the interviews, an ethics assessment form from the university was filled in. After the approval of the Ethics Committee and the supervisor(s), the interviewees were contacted. In contacting possible interviewees, information about the research regarding nature, method, and purpose was provided. In case possible interviewees agreed to be interviewed they received consent before the actual interview starts, consent forms are found in Appendix II. In this consent form, they were able to give their preference about what information (name, function &/ or company name) of them would be shown within the research report and what not, which could also be changed at any time. Interviewees also could, at any time, terminate their participation within the research. Personal data was stored at an external hard drive which was not moved out of the building where the research was written. Personal/identifiable data were destroyed when the research was completely finished. The interviewees were informed about the results of the research in case they wanted to.

3.5 Data Analysis

This was qualitative research; only qualitative methods were used to analyze the data used in the study. The table below describes the analyses of research materials.

Information required to answer the question	**Data Analysis**
Operating principle, Weight, cost of installation and maintenance, the capacity of water and vegetation.	Qualitative: Analysis of the features of each roof
Ecological benefits such as reduce noise and air pollution, sequester carbon, increase urban biodiversity by providing habitat for wildlife	Qualitative: Analysis of ecological benefits of each roof and how they enable adaptation
Economic benefits such as payback period by reducing the energy consumption	Qualitative: Analysis of the economic benefits of each roof
Socio-cultural benefits	Qualitative: Analysis of the socio-cultural benefits of each roof
Features, ecosystem services and economic benefits of each roof	Qualitative: Analysis of strengths and weaknesses based on their features, ecological, economic and socio-cultural benefits

Table 2 Data analysis

3.5.1 Data validation

To avoid their own interpretations and bias of the researcher the data collected from interviews will be compared with the data collected from scientific literature and documents. This will be done as much as possible. However, this is mainly exploratory research, and therefore validation might not be possible for all the collected data. Parts of the data collected from the interviews will also crosscheck with informants from other organizations, who were involved in the green infrastructures.

3.5.2 Analytical framework

As illustrated in Figure 6, the analytical framework shows the generation and analysis of data in accordance with the proposed research framework for the attaining of the research objective.

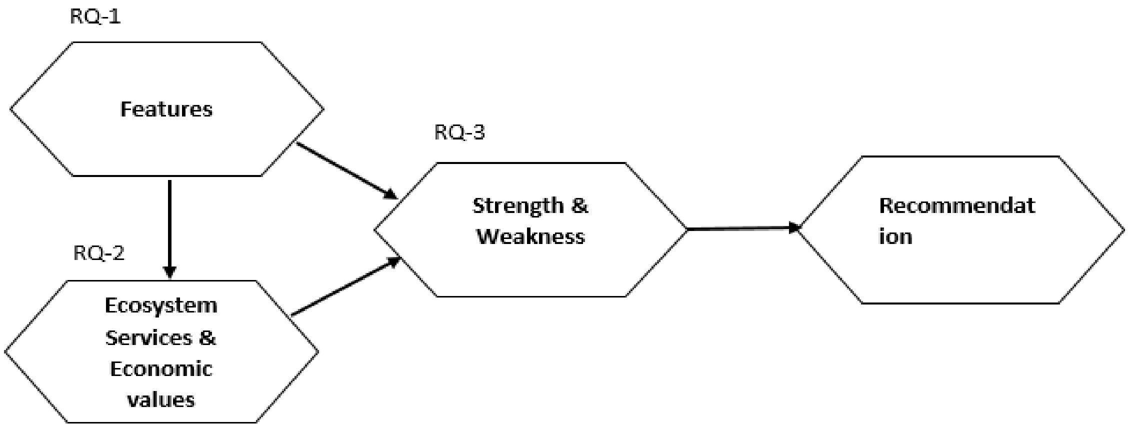

Figure 6 Analytical framework

The first step is the analysis of features of different green infrastructure methods of De Dakdokters, which answers the first sub-question. The features analyzed are operating principle, weight, cost of installation and capacity to store water. This is followed by the analysis of the ecosystem services provided from the perspective of ecological, economic and socio-cultural benefits. Identifying the ecosystem services of green infrastructure methods of De Dakdokters that contribute to urban climate change adaptation answer the second sub-question. The benefits were identified from the literature review and cross-checked with the data obtained from the interviews. Based on the data obtained from the interview and the data from the documents reviewed, tables were formulated in which the range of benefits for each green infrastructure method was presented. The analyzed economic benefits are energy reduction, roof longevity, payback, and incentives. The ecological benefits analysed are rainwater buffer, air purification, reduce ambient temperature and noise, increase biodiversity and erosion protection. Impacts on social coherence and improved health are analyzed as there are the benefits of socio-cultural. Analysis of the features and ecosystem services provided by the green roofs facilitated the identification of the strengths and weaknesses of each method. The results from this analysis answer the third sub-question by enabling the formulation of recommendations. By answering all the sub-questions, the main question is answered, hence the research objective is achieved.

Chapter 4 Features of Green Infrastructure Methods

In this chapter, the operating principle, capital cost, weight, and capacity to store water of each green infrastructure methods are described. The data in this chapter is based on the data collected from the interview as well as the data available from the documents reviewed. In this chapter, an answer is given to the first sub-question of the thesis.

4.1 Green Roof

The practice of growing green vegetation on the roof directly over a waterproof membrane is called green roof. The most common variety of green roofs are intensive and extensive roofing. The intensive variety includes a thick layer of soil that can support large vegetation such as small trees. The vegetation is characterized by the presence of bushes and trees, optionally in combination with a lawn and/or ground cover. In this form of roof vegetation, intensive maintenance is required, including watering, trimming, fertilizing and weeding. Extensive roofing's are characterized by their thinner layer of soil and smaller plants. The vegetation develops into a more or less ecologically stable plant community that sustains itself with a minimum of maintenance.

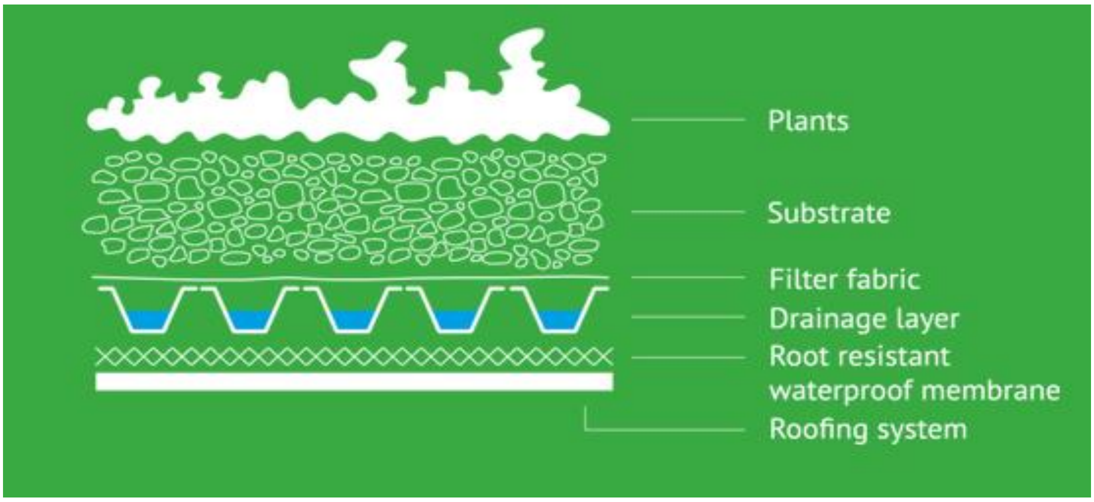

Figure 7 Green roof source: https://dakdokters.nl/en/green-roofs/

The capital cost of a green roof varies depending on the type, the price ranges from a minimum of 35 euros to maximum of 55 Euros/m^2. Based on the type of green roof used the weight ranges between 60 L/m^2 as the basis to a maximum of 200 kg/m^2. Their capacity to store water is given as 30 L/m^2 to 150 L/m^2 based on the type of green roof used.

Type	Price (Euro/m^2)	Water capacity (L/m^2)	Weight (kg/m^2)
Basic green roof	35	30-150	60-90
Biodiverse green roof	40	40-150	120
Shade roof	40	40-150	120
Landscape roof	55	70-150	200

4.2 Roof Garden

A roof garden is similar to green roof technique that placed in a container garden on a roof as a basic type, helps in bringing green life back in urban areas. A roof garden is a kind of outside patio area – however on top of a roof, almost something can domesticate into a floor-stage patio may be mounted on a roof. The roof garden is a stability of the ecology cycle and has a high-quality landscape inside the urban area, urban agriculture is a way to sustainable improvement with the potential of offering meals or applicable offerings in urban areas.

Figure 8 Roof garden *source: https://www.noblerotpdx.com/web/garden/*

Even though the roof garden is similar to the green roof, but the structure of the rood garden is exclusive. Commonly used wood decks are Thermowood and Bamboo Xtreme. Whereas, Bamboo costs twice that of Thermowood costs, which makes a huge difference in the price range. So, the capital cost of the roof garden ranges between 250-1000 Euros/m^2. The average weight of the roof garden is about 70-100 kg/m^2. The roof garden provides space to move along the garden and so the capacity to store water is low when compared to green roof. From this their capacity to store water ranges between 30-100 L/m^2.

Type	Price (Euro/m^2)	Water capacity (L/m^2)	Weight (kg/m^2)
Roof park	250-1000	30-100	70-100

4.3 Polder Roof

The polder roof is comprised of a system of crates that can store water. The basin that comes into existence can be dynamically controlled (De Dakdokters, 2017). Along these lines, the polder roof is competent to store water and channel it at a later preferred time, by this water flooding the city is prevented.

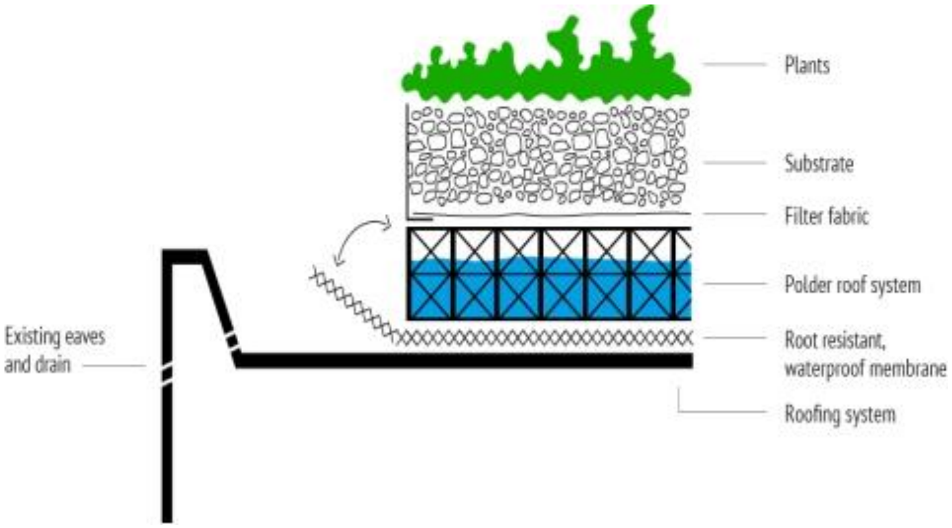

Figure 9 Polder roof *source: https://dakdokters.nl/en/green-roofs/*

Performances of the polder roof are monitored online, and the system can be regulated from a distance by real-time information about rainfall, storage, and drainage, historical database. Controlled water level by provides dynamic control of water drainage, safety setups for storage and frost: 100% safe, entirely powered by solar energy. The capital cost of the polder roof is about 50-60 Euros/m^2. The weight of the roof ranges between 90–120 kg/m^2, while their capacity to store water is around 135 L/m^2.

Type	Price (Euro/m^2)	Water capacity (L/m^2)	Weight (kg/m^2)
Roof park	50-60	135	90-120

4.4 Roof Park

A roof park is a combination of intensive green vegetation with the space available at the roof in a semi-public roof. The addition of roof park to the building increases sustainability and create multifunctional spaces, that provide the possibility for a vegetable garden, intensive green with water features, and city beach on the roof. Even though the roof park is similar to the roof garden, the green area in roof park is relatively low when compared to the roof garden. Furthermore, the roof park offers an attractive spot for butterflies and bees, storage for rainwater and cooling for buildings.

Figure 10 Roof park Source: http://www.landezine.com/index.php/2015/10/rooftop-park-/

By creating a roof park, extra space is created to relax, have meetings and have lunch while getting fresh air. Since the roof park is similar to the roof garden, the price and capacity to store water are same in both methods. The capital cost of the roof park is same as that of roof garden ranging from 250-100 Euros/m^2. The weight of the roof park is between 60-90 L/m^2 and its capacity to store water is 30-100 L/m^2.

Type	Price (Euro/m^2)	Water capacity (L/m^2)	Weight (kg/m^2)
Roof park	250-1000	30-100	60-90

Chapter 5 Benefits of Green Infrastructure Methods

In this chapter the benefits of each roof are discussed in terms of 1) Ecological benefits, 2) Economical Benefits, 3) Socio-cultural benefits. Under each category, the benefits have been explained for each individual roofing methods used by De Dakdokters

5.1 Ecological Benefits

Among the most common benefits of having a green infrastructure are rainwater buffer, air purification, reduction of ambient noise and ambient temperature, increase longevity of roofing membranes, increase urban biodiversity by providing habitat for wildlife, sequester carbon, provides space for urban agriculture, provide a more aesthetically pleasing and healthy environment to work and live. Some of the common ecological benefits of green roofing methods of De Dakdokters are given below.

Table 3 Description of ecological benefits

Ecological Benefits	**Description** (Sempergreen, 2019)
Rainwater buffer	Green infrastructure is able to offer buffering services through storage of water in the vegetation present, drainage layer and substrate. This enables the delay in discharging of rainwater to sewage system, purification of water and reduction of water quantity through evaporation from plants. They have a holding rate range of 50%-90% depending on design. For the sewage system it decreases peak capacity, stabilize groundwater level and reduce flood risk, consequently decreasing strain on street drainage systems and facilitating stormwater management.
Air purification	It contributes to air purification by reducing the velocity of airflow using foliar surfaces located on green infrastructure. Which filters about 10%-20% of the debris found in the air hence purifying it. Moreover, as rainwater permeates through the several layered green infrastructures, it filters nitrates enabling water quality improvement.
Reduce ambient temperature	The plant's ability to absorb sunlight for photosynthesis creates a cooling effect in its vicinity. The main advantage of this is reducing of cooling need which translates to less use of air conditioners hence energy saving. Furthermore, this effect affects the adjacent vicinity of the building and the overall temperature of the locality by about 3°C reduction.
Reduce ambient noise	Due to population and development most, urban areas are characterized by loud noises and sounds. Green infrastructure is able to absorb, reflect, deflect sound waves thus acting as sound barriers. They have a capacity of sound reflection of 3 decibels and soundproofing of 8 decibels thus protecting people from noise pollution.

Increase urban biodiversity	The presence of green plants (host plants, grass and herbs) in the green infrastructure creates supporting habitat conditions for insects and butterflies. This promotes habitat life in urban environment thereby increasing the urban biodiversity and protection of native species.
Erosion protection	The pre-cultivated vegetation has a blanketing effect of protecting substrate layer from being eroded during strong winds such as storms thus providing an erosion resistance property to green infrastructure.

5.1.1 Green roof

A green roof commonly referred to as a living roof has a complete vegetation layer covering the rooftop. They serve multiple purposes among them are mitigation of heat island effect and reduction of noise through deflection, reflection and absorption of sound waves due the combination of soil and plants. In addition, it also serves in rainwater buffering, reducing urban temperature, air purification, increasing urban biodiversity and also minimize stress by providing aesthetically pleasing landscape. They are suitable for retrofitting projects as well as in new development projects. They can be applied at a variety of range from small range like garages to large ranges like commercial buildings. Lastly green roof has water purification effect and increases the lifespan of building material and technologies such as waterproofing membranes, air conditioning systems and ventilation.

Green roof benefits	High	Medium	Low
Rainwater buffer		✔	
Air purification	✔		
Reduce ambient temperature	✔		
Reduce ambient noise		✔	
Increase urban biodiversity	✔		
Erosion protection		✔	

Table 4 Green roof ecological benefits

5.1.2 Roof garden

The roof garden has aesthetically effects from having great view and decoration. They also have air purification effect due to their filtration of air particles and deposition in the growing space. Roof garden contributes to adaptation to urban heat island effect through the daily evaporation cycle which has cooling effect on its surroundings. Another initiative of roof garden is urban agriculture that functions as miniature farms producing fresh food products. The combination of plant and soil provided by roof garden reduces the ambient temperature and noise from the surroundings by absorption, deflection and reflection. Apart from the types of plants, trees, and invertebrates that can be harvested on the roof garden, they also provide a perfect habitat for insects, birds and stopover location for migrating species. The roof garden has similar benefits as the green roof but isn't effective in capturing the rainwater and insulation of the building.

Roof garden benefits	High	Medium	Low
Rainwater buffer			✔
Air purification	✔		
Reduce ambient temperature		✔	
Reduce ambient noise		✔	
Increase urban biodiversity	✔		
Erosion protection			✔

Table 5 Roof garden ecological benefits

5.1.3 Polder roof

Polder roof gives the ability to collect and storing of rainwater to flat grey roof. It is an innovative method with controllable water storage and drainage system that can accommodate crops, solar panels and recreational activities. Polder roof is best suitable for water buffering and has an added advantage of controllability that isn't found in other green infrastructures. Other green infrastructures such as green roof once saturated, they cannot store rainwater, they can only delay its runoff. Polder roof also allows the utilization of the stored water for other uses, thereby making it very suitable for water buffering. Apart from water buffering, it has the benefit of air purification, reduce temperature and noise, erosion protection and increase biodiversity in the urban landscape. The polder roof functions as a foundation for a green roof, roof garden, solar park or roof park.

Polder roof benefits	High	Medium	Low
Rainwater buffer	✔		
Air purification		✔	
Reduce ambient temperature		✔	
Reduce ambient noise			✔
Increase urban biodiversity		✔	
Erosion protection		✔	

Table 6 Polder roof ecological benefits

5.1.4 Roof park

Roof park provides contact with nature in places where that has become a bit of a luxury, such as in big crowded cities. It also decreases pollution levels and the increases water and air quality plus reduces the stress level. In addition, thermal resistance of roof is increased throughout the year with most benefits during summer months as it helps in reducing cooling costs, saving fuel and also reduced noise levels using reflective sound. Plants absorbs carbon dioxide from the air and also trap up to 85% of airborne particulates on their leaf surfaces. When the park planted with indigenous flora, can provide important habitats for native bird and insect populations. Roof park when installed properly have a substantially longer life span than conventional grey roofs. Due to the smaller temperature fluctuations, the roof is subjected to less wear and tear from natural elements and also protected from UV radiation and mechanical damage by green layer.

Roof park benefits	High	Medium	Low
Rainwater buffer		✔	
Air purification		✔	
Reduce ambient temperature		✔	
Reduce ambient noise			✔
Increase urban biodiversity		✔	
Erosion protection			✔

Table 7 Roof park ecological benefits

5.2 Economic Benefits

The green infrastructure methods are well-suited for urban areas, as they provide excellent value for money at both individual and public levels in comparison with other currently available grey infrastructure. However, the high initial investment required for green infrastructure acts as a barrier to their market penetration, there are many economic benefits that can make up for this. Although green infrastructure is not simple or cheap, many cities recognize that long-term benefits outweigh the initial cost concerns. In general, individual benefits of a green infrastructure include a reduction in energy use for heating and cooling, membrane longevity, acoustic insulation, and aesthetic benefits. Public benefits include reduction of stormwater runoff, improvement of air quality, mitigation of urban heat island effect, and increment of urban biodiversity. A green workplace has potential of increasing productivity up to 15%, as plants have a positive effect on people and also reflected in employee satisfaction. In Amsterdam people are allowed to add a rooftop house of max. 6m2 to facilitate access to the roof. This 6m2 will be added to the used surface (m2) of the house and can add up to 10.000 euros to the price of the house.

Table 8 Description of economic benefits

Economic benefits	**Description** (Technical Preservation Services, National Park Service, 2019)
Energy reduction	Green infrastructure reduces energy consumption in space heating through shading, evapotranspiration, insulation, increase in thermal mass, and reduction of heat loss through radiation. Green infrastructure can also be more efficient in preventing heat loss in the winter compared with conventional roofs. The reduction in energy bills is usually the most convincing factor for building owners to install green infrastructure.
Roof longevity	Green infrastructure can make bigger the lifespan of a roof by over 200 % through protecting the waterproofing membrane with growing medium and plants, which shields the membrane from ultra-violet (UV) radiation and physical harm. Green infrastructure will increase the lifespan of a building's roof by protecting towards diurnal fluctuations, UV radiation, and thermal pressure. The life of the roofing membrane may be effortlessly lengthened up to 40 to 50 years through green infrastructure while a conventional roof's lifespan ranges from 10 to 30 years.
Reduced stormwater	Green infrastructure can affect the stormwater retention capacity of the building. With the presence of green infrastructure, the rainwater that falls onto the roof surfaces flows into the sewers at a slower price, as green infrastructure is capable of preserve water. Based on the retention overall performance of green infrastructure it will be capable of creating financial savings per 12 months by reducing the public infrastructure management charges.
Urban biodiversity	Green infrastructure can help to improve biodiversity by creating additional habitat for animals. However, the additional habitat for animals is treated only as a bonus in comparison with different quantifiable blessings. It is not easy to quantify the improvement in biodiversity and estimate the corresponding costs and benefits using a commonplace technique. While it is difficult to directly quantify the economic benefits of habitat increase due to green infrastructure, the resulting environmental benefits may be translatable to economic terms such as pollination by bee enabling reproduction of plants, sight-seeing and, incentives.

5.2.1 Green roof

Green roofs reduce energy consumption through insulation, increase in thermal mass, and reduction of heat loss through radiation. Green roofs also are more efficient in preventing heat loss in the winter compared with conventional roofs. They increase the lifespan of a building roof by protecting against UV radiation, and thermal stress, thus the lifetime of roofing membrane easily lengthened. The green roof provides stormwater retention and urban biodiversity but calculating the economic aspect of these are complex but it is possible.

Green roof benefits	High	Medium	Low
Energy reduction	✓		
Roof longevity	✓		
Reduce stormwater		✓	
Urban biodiversity		✓	

Table 9 Green roof economic benefits

5.2.2 Roof garden

As discussed earlier in chapter 4 the roof garden is as similar to the green roof technique, except that it is placed in a container garden on a roof as a basic type. The economic benefits of the roof garden are somewhat similar to that of a green roof. As they provide insulation of roof, reduce heat loss through radiation results in reducing the energy consumption and protects the roofs from UV radiation thus increasing the lifespan of the roof. It also provides stormwater retention and urban biodiversity.

Roof garden benefits	High	Medium	Low
Energy reduction	✓		
Roof longevity	✓		
Reduce stormwater		✓	
Urban biodiversity		✓	

Table 10 Roof garden economic benefits

5.2.3 Polder roof

Polder roof is best suitable for stormwater retention as it is specially designed for storing the rainwater and utilizing it later for irrigation. Polder roof also provides other economic benefits such as energy reduction, roof longevity, and urban biodiversity but they reduce stormwater is the main economic benefit.

Polder roof benefits	High	Medium	Low
Energy reduction		✓	
Roof longevity		✓	

Reduce stormwater	✓		
Urban biodiversity			✓

Table 11 Polder roof economic benefit

5.2.4 Roof park

The economic benefits of roof parks are not as high as other roofing methods since the area of green space is low when compared to the other green infrastructure methods. Since the green space is low, energy reduction, reduce stormwater, roof longevity and urban biodiversity by this method is very low. But roof park has several socio-cultural benefits, which are lacking in the other green infrastructure methods.

Roof park benefits	High	Medium	Low
Energy reduction			✓
Roof longevity			✓
Reduce stormwater			✓
Urban biodiversity			✓

Table 12 Roof park economic benefits

5.2.5 Payback and incentives

Economic benefits of green infrastructure rely on their performance. The operation and maintenance of vegetative roofs are critical in securing their positive impacts. Maintenance cost depends on the size of green infrastructure, the characteristics of the building, the complexity of the green infrastructure system, the type of vegetation, as well as the market operation and maintenance price. As mentioned earlier, it's hard to tell payback period itself, as strongly context depending. The payback periods in the market with average initial costs are shorter than the lifespan of green infrastructure. It shouldn't always be considered a tool for the return of investment. On the contrary, it's slowly being considered a necessary way to create green, public space and nature in cities. Due to urbanization, this starts to become so relevant that municipalities and governments start prescribing requirements that must be met. Especially for water management this is relevant. More and more for newly build buildings a rain shower of 60mm must be processed on own plot: Polder roof can be the answer to that. The changing weather conditions due to climate change already produce more heavy rain showers, the Dutch sewer system is not built for that.

The government of the Netherlands provides incentives when certain conditions are met, up to 50% for green roofs (of any kind), only for existing buildings of at least 5 years of age. Also, there are possibilities for a 'sustainability loan' (loan with a low rate of interest), if proven new building meets some sustainable requirements, like water buffering, insulation, etc. These initiatives open up the sector to lots of new opportunities for green employment and economic development. Ranging from research and development jobs to installation and maintenance there is great potential to create employment and stimulate the economy.

5.3 Socio-Cultural Benefits

Apart from their sustainable aspects, green infrastructure can be a beautiful addition to buildings and designated as public place for building residents and guests. Presence of public place increases public safety and sense of unity in the community. Working and living in a green environment has a positive effect on the well-being of people as greenery offers relaxation and reduces stress. As for patients it boosts recovery rate, increase tolerance to pain enabling fast discharge from hospital, this phenomenon is termed as 'healing environment'. Lastly the green environments/zones bring community cohesion and public safety by providing higher perception, user experience and being less prone to aggression, violence, and vandalism. With a larger implementation scale, the socio-cultural benefits of green infrastructure will increase tremendously.

Table 13 Description of the socio-cultural benefits

Socio-cultural benefits	**Description** (Sempergreen, 2019)
Social cohesion	Green infrastructure re-creates the lost connection with public space. The social life of people living in the neighbourhood will improve as it provides a recreational space, community garden and place to meet and relax. This leads to a strengthening of social cohesion.
Healthy environment	A healthy living environment with good air quality, cooling, the presence of possibilities to exercise, etc., leads to fewer health problems. In addition, a view on greenery reduces stress and helps the mind to relax which improves the health condition.
Less vandalism	Zones with greener surface are subjected to less violence, vandalism and aggression, which has positive effect on social coherence. Furthermore, they tend to give a higher perception and user experience in a living as well as working environment.

The green roof, roof garden, and polder roof use the maximum space in a roof to create green space thus minimizing the space for human interaction. The socio-cultural benefits of these three methods are very low as they provide less space for human connection, but the socio-cultural benefit of roof park is high since the green space in this method is less. The roof park provides space for employees and renters a relaxation area, neighbourhood public space, outdoor exercising area, and so on. The green space on the roof park has a strong and soothing influence on the mood of the occupants such as tenants, employees or guests. Whilst, office managers and owners are looking ways to offer a greener working environment for employees which increases their productivity.

Chapter 6 Comparison of Green Infrastructure Methods

In this chapter, both the strength and weaknesses of each green infrastructure method are described and compared based on the assessment of benefits presented in chapter 5. Looking pleasant and being energy efficient and environmentally friendly too, green infrastructure better utilizes an often-neglected area. Green infrastructure is covered with plants and vegetation, bringing a number of excellent benefits to every building. They also offer several benefits, but it's also important to look at the potential drawbacks. When understanding the potential disadvantages of green infrastructure, fully informed a decision about whether or not to start planting on the roof can be decided. In spite of a few disadvantages, several strengths of the green infrastructure encourage many users to install greenery on their grey roof.

6.1 Overall Strengths

As discussed in the earlier sections, few advantages of having a green infrastructure are explained. Insulating qualities: not only does a green infrastructure insulate noise, but it also keeps warmth inside or outside during winter and summer. The life-span of the roof is at least doubled because of the vegetation's protective effect. Green infrastructure contributes to the reduction of carbon dioxide emissions. Next, to that, they filter particulate matter and help to improve the quality of the air this way. Green infrastructure absorbs rainwater very well and gives it off slowly (Hashemi, Mahmud & Ashraf, 2015). Consequently, the pressure on the sewer will be lower in case of heavy rain showers.

- Improve the drainage system

Sustainable drainage is a crucial component of any building, as a manner to counter flooding inside the occasion of excess rainfall. Traditionally, a network of pipes related to the sewage system has helped manage water. But, because of increasing urban development, as a whole lot as 75% of water is walking off into urban regions. To counter this danger, green infrastructure is an outstanding alternative, where water is saved in vegetation and substrate, earlier than being launched again into the surroundings certainly.

- Increases lifespan of the roof

The rooftop is constantly under attack by various natural elements and needs to cope throughout the year. The various elements that attacks the roof are not only wind and rain but also by ultraviolet light and fluctuating temperatures too. As such, it's common for each house owners and agencies to bear in mind an alternative for the roof. Green infrastructure gives this possibility and has proved to double or even triple the lifestyles expectancy of your rooftop.

- Boosting thermal performance

Without any doubt, one of the green infrastructure's most beneficial advantage is thermal performance and it's marvellous simply how much of a distinction this will make. One among the largest troubles going through an ordinary roof is terrible insulation, leading to big warmness loss in iciness and sweltering conditions over the summer season months. This all modifications with the aid of green infrastructure. By means of implementing green infrastructure, it's far ensured to enhance strength efficiency and restriction the use of air conditioning too.

- Supporting wildlife habitats

Green infrastructure supports wildlife and in turn helps in creating a better healthy habitat. At the same time, it won't replace ground environment directly and they're best for attracting birds, different flora and fauna to create a thriving eco-friendly habitat. Each green infrastructure will guide various habitats, established largely at the kind of plant life included.

- Improving the air quality

Air pollution remains an important issue, as you would expect, air pollution is a greater problem in urban areas, especially the larger cities. Green infrastructure helps to improve the overall air quality.

6.2 Overall Weaknesses

Although the advantages speak for themselves, there are drawbacks that need to be considered before making an investment into green infrastructure (Hashemi, Mahmud & Ashraf, 2015). Even though it is not much, a green infrastructure still requires maintenance, depending on the type, considerable costs may be involved. Leaks are harder to trace and fix, weed may appear on green infrastructure as well. This is particularly true for a garden roof, although other green infrastructure may have to deal with it too.

- A greater expense than traditional roofs

Unfortunately for green infrastructure, they do have a tendency to be slightly greater pricey than the traditional option. One of the widespread reasons for this being the greater help required to deal with the accelerated load. No matter the more initial setback, over time these roofs extra than make up for the outlay. When you keep in mind the range of superb blessings highlighted earlier, there should be no purpose to permit fee to play a figuring out position in your choice.

- An increase in weight load

There's no doubt green infrastructure is heavier, require extra structural support to be carried out. It affects the shape of the prevailing constructing 1) the weight on the muse, a roof terrace ought to not add over 5% of the whole constructing weight so as for the inspiration now not to be tested. therefore: the better the building, the more weight can be brought on the inspiration which is by no means a problem. 2) the roof bundle desires in order to bring the burden. that is almost never viable (in current homes), in view that a roof isn't calculated and built for use, not to mention green, substrate, and so forth.

If the existing roof isn't always sufficient, there are two options: a) create a separate secondary structure from load-bearing wall to load-bearing wall (like steel beams that bring timber beams in among, that deliver the deck and the interior/humans/fencing), or b) improve the roof through making the existing beams thicker (to cleat): handiest viable with wood. Reinforcing a concrete ground is possible, but high priced and harder. Although a few rooftops will need to be retrofitted to cope with the boom in load, thankfully flat roofs are frequently capable of manage this potential.

- Damage from leaks

Even though most green infrastructure encompasses a root barrier layer, the roots of plants once in a while penetrate the water-resistant membrane, causing roof leaks that might result in structural harm. A yearly inspection to cast off complex shrubs facilitates to lessen the potential for growing leaks. The use of a shallow developing medium normally prevents any vegetation from growing large enough to develop a strong, deep root system. Because the green infrastructure meeting is so complex, locating the source of a leak repairing it can be a difficult process. green infrastructure installers can carry out flood assessments at once after the installation or restore of a roof to check for leaks.

- Extra maintenance requirement

There is an on-going debate with regard to the quantity of renovation required for a green infrastructure, whoever it agreed that extra maintenance is required for its operation. Green infrastructure should be treated as a garden and as such, it will require watering, feeding, and weeding. With a green infrastructure there are by far greater benefits for implementing one and as such, serious consideration should be given.

6.3 Strengths and Weaknesses of Each Method

The strengths and weaknesses of the green roof, roof garden, polder roof, and roof park are described below.

6.3.1 Green roof

- Strengths: The green roof improves the air quality of the surroundings, provides a better drainage system for stormwater management. Since it provides a stormwater management system the run-off is reduced and helps in erosion protection. It increases biodiversity in the urban area and the lifespan of the roofs is the strength of the green roof.

-Weaknesses: There are several weaknesses of green roofs. They are more expensive than traditional roofs and incurs additional maintenance costs apart from the initial capital cost. Membrane leakages cause damage to the roof and it is problematic to pinpoint the leakage. Green roof causes structural damage to building as they are heavier; though the weight might differ based on the type of roof.

6.3.2 Roof garden

- Strengths: The strength of the roof garden is quite similar to that of the green roof, rainwater buffer to minimize the runoff, erosion protection as the runoff is minimized. Better air quality as the plant removes air particulates and provides shade. Roof garden absorbs and traps heat thus reduces the urban heat island effect, increases the roof longevity and biodiversity.

-Weaknesses: Some buildings aren’t strong enough to support the added weight of the roof garden, so there are structural limitations and damage to the roof due to membrane leakages. High capital cost, as well as extra maintenance cost, makes roof garden expensive to have. Limited choice of plant is another weakness, the thick growing medium of intensive roofs can support wide range of plants that includes small tree and shrubs. Extensive roofs, however, can typically only accommodate a small selection of drought-tolerant plants with shallow root systems. Less robust plants also have trouble surviving the strong winds on high rooftops.

6.3.3 Polder roof

-Strengths: Improved drainage system in an urban area as the polder roof provides a strong system for stormwater management among the four green infrastructure methods. This, in turn, contributes to low runoff water and protects soil from erosion. Polder roof also provides improved air quality, increase in urban biodiversity, reduces the urban heat island effect and longevity of the roof.

-Weakness: The capital cost polder roof is more expensive than other methods since they use sensors for continuous monitoring of the water flow and maintenance. There is a possibility of damage from the leak and structural damage due to weight of the roof.

6.3.4 Roof park

-Strength: Re-creates connection through being a public space and improves the social life of the people. It also gives a healthy environment with fresh air, helps in reducing stress and relaxation. Increases the longevity of the roof and urban biodiversity, it also provides rainwater buffer, erosion protection but they aren't as high when compared to the other green infrastructure methods.

-Weaknesses: Limited choice of plants based on the thickness of the growing medium, limitation in the structure due to the weight of the roof and requires additional maintenance cost.

7 Conclusion and Recommendations

7.1 Conclusions

Climate change is one of the most challenging problems in urban areas. Periods of heavy rainfall and droughts do have large negative effects within urban areas. Several countries worldwide are already doing efforts to become climate-resilient. Green infrastructure helps adapt to the problems that cities are facing by bringing the natural cooling and water-treatment capabilities of undeveloped areas into the urban environment. This study addresses the operating principle, capital cost, weight, and capacity to store water of green infrastructure methods of De Dakdokters. Dakdokters has four types of green infrastructure which are a green roof, roof garden, polder roof, and roof park. Among the four types of roof, the one with lowest capital cost was green roof (35-50 Euro's per m^2), with lowest weigh range was roof park (60-90 kg/m^2), and highest water capacity was polder roof (135 L/m^2).

Following the structure and features of the green infrastructure methods of De Dakdokters, the study addresses the economic, ecological and socio-cultural benefits in adapting urban climate change. Based on the interview conducted and the in-depth literature review, several benefits were identified. The economic benefits of the four methods are reduction in energy use for heating and cooling, membrane longevity, reduce stormwater, improve urban biodiversity, payback and incentives. This initiative opens up the sector to lots of new opportunities for green employment and economic development. The ecological benefits are rainwater buffer, air purification, reduction of ambient temperature and ambient noise, increase of urban biodiversity, erosion protection and roof longevity. The contribution of each green infrastructure method in providing the above-mentioned benefits is summarized chapter 5. The socio-cultural benefits are positive effects on well-being, reduces stress, relaxation, fast recovery for patient and brings local people together. Areas with more greenery tend to be associated with less aggression, violence, and vandalism.

The study also focused on the strength and weaknesses of a green infrastructure method of existing buildings. The strengths identified were improving the drainage system, increase the lifespan of the roof, boosting thermal performance, supporting wildlife habitats, air purification and helping out the environment. Green roofs offer several benefits, but it's also important to look at the potential drawbacks such as damage from leaks, requires extra maintenance, increase in weight load, expensive than traditional roofs and limited choice of plants.

Thus, all the three sub-questions were answered in the research, in order to make a recommendation for improving the green infrastructure methods which answer the main research question.

7.2 Recommendations

The main question of the research was 'How can the contribution of green infrastructure methods of De Dakdokters to urban climate change adaptation in the Netherlands be improved?' From the research findings, the recommended improvements are 1) Extensive roofing with continuous coverage of growing media over at least 75% of the roof footprint of the building. 2) Based on the annual average rainfall, the roofing system should have maximum runoff coefficient. 3) Existing building analysis must be conducted to know the structural load limitation. Based on that the depth, type of growing medium and plant can be determined. 4) There is also very little research and literature focusing on green infrastructure failures. By learning from miscalculations in roof design, the same errors could be avoided in future roofs. 5) Propagating and testing the roof potentials could develop robust green infrastructure plant communities. Many of these plant communities are threatened, which could add to the benefits of green infrastructure supporting them.

Apart from the above-recommended improvements for De Dakdokters green infrastructure methods, the study also has the following recommendation for future research; 1) Interviews can be conducted with other companies that are involved in the green infrastructure to improve the validity of the results. 2) Focus should be directed to analyse public-private partnerships and awareness level as an approach to promote and develop quality standards for green infrastructure.

Overall the study has identified the associated economic, social and ecological benefits of different green infrastructure methods towards adaptation to urban climate change. Furthermore, it has identified the strength and weaknesses of each of the green infrastructure and provided recommendations for improvement of their adapting capacity. Thus, the research has been able to attain its desired objective and has contributed knowledge in understanding the services of the green infrastructure of De Dakdokters. Lastly, green infrastructure is an important factor that cannot be neglected when trying to achieve sustainable environments because of its importance to urban areas and the world at large.

References

Anonymous. (2019). *Ecosystem change* Retrieved from https://www.greenfacts.org/en/ecosystems/millennium-assessment-2/4-factors-changes.html

Bell, R., Berghage, R., Doshi, H., Goo, R., Hitchcock, D., Lewis, M., Liptan, T., Liu, K., McPherson, G., Nowak, D., Peck, S., Taube, B., Velazquez, L., Wolf, K., Yarbrough, J., Zalph, B., (2013). *Reducing urban heat islands: Compendium of strategies, green infrastructures*. Environmental Protection Agency, US.

Benedict, M.A., & McMahon, E.T. (2002). *Green infrastructure: Smart conservation for the 21st century*. Sprawl Watch Clearing House Monograph Series, 7-8.

Bolund, P., & Hunhammar, S. (1999). *Ecosystem services in urban areas*. Ecological Economics, 29(2), 293-301. doi: 10.1016/s0921-8009(99)00013-0

Carleton, W.C., Campbell, D. & Collard, M. (2017*). Increasing temperature exacerbated classic Maya conflict over the long term*. Quaternary Science Reviews, 163, 209-218

Carpenter, S.R. (2003) *Regime shifts in lake ecosystems: Pattern and variation*, Ecology Institute

Carpenter, S., & Folke, C. (2006). *Ecology for transformation*. Trends in Ecology & Evolution, 21(6), 309-315. doi: 10.1016/j.tree.2006.02.007

Davis, S. J., Caldeira, K., & Matthews, H. D. (2010). *Future CO2 emissions and climate change from existing energy infrastructure*. *Science*, *329*(5997), 1330-1333

De Dakdokters. (2017). *De Dakdokters - We make cities healthy!* Retrieved from https://dakdokters.nl/en/

Dickinson, D., & Hobbs, R. (2017*). Cultural ecosystem services: Characteristics, challenges and lessons for urban green space research*. Ecosystem Services, 25, 179-194. doi: 10.1016/j.ecoser.2017.04.014

Elmqvist, T., Wall, M., Berggren. A., Blix, L., Fritioff, A., Rinman, U. (2001) *Tropical forest reorganization after cyclone and fire disturbance in Samoa: Remnant trees as biological legacies*. Conservation Ecology. 5, 10

Emilsson, T., & Sang, Å.O. (2017). *Impacts of climate change on urban areas and nature-based solutions for adaptation*. In Nature-Based Solutions to Climate Change Adaptation in Urban Areas. Springer, Cham, 15-27.

European Commission. (2016). *Green infrastructure*. Retrieved from http://ec.europa.eu/environment/nature/ecosystems/index_en.htm

Hashemi, S., Mahmud, H., & Ashraf, M. (2015*). Performance of green roofs with respect to water quality and reduction of energy consumption in tropics: A review*. Renewable and Sustainable Energy Reviews, 52, 669-679. doi: 10.1016/j.rser.2015.07.163

Hondula, D., Balling, R., Vanos, J., & Georgescu, M. (2015). *Rising temperatures, human health, and the role of adaptation*. Current Climate Change Reports, 1(3), 144-154. doi: 10.1007/s40641-015-0016-4

Hooper, D.U. et al. (2005) *Effects of biodiversity on ecosystem functioning: a consensus of current knowledge*. Ecological Monographs. 75, 3–35

James, P., Tzoulas, K., Adams, M. D., Barber, A., Box, J., Breuste, J., ... & Handley, J. (2009). *Towards an integrated understanding of green space in the European built environment*. Urban Forestry & Urban Greening, *8*(2), 65-75.

Jarrin, V., Hilarides, A., Jourdain, E., Magdy, S., Ferreira, R. N., Wijaya, S. S. R., … Zhao, Y., Alagumannan, P., Dsouza, S., Kumar, S., Wu, X., (2019). *Water-based ecosystem services in Friesland: An examination and analysis of best practices and potential for upscaling provisioning ecosystem services group*. MEEM Programme, University of Twente, The Netherlands.

Kerssen, A.J. (2019). *Green roofs and living walls in the Netherlands*. Retrieved from https://livingroofs.org/green-roofs-in-the-netherlands/

Kirchhoff, T. (2019). *Abandoning the concept of cultural ecosystem services, or against natural–scientific imperialism*. Bioscience, 69(3), 220-227. doi: 10.1093/biosci/biz007

Kowarik, I. (2011). *Novel urban ecosystems, biodiversity, and conservation*. Environmental Pollution, 159(8-9), 1974-1983. doi: 10.1016/j.envpol.2011.02.022

KNMI. (2014). *Klimaatscenario's voor Nederland*. Retrieved from http://www.klimaatscenarios.nl/brochures/images/KNMI14_Klimaatscenarios_folder_2015.pdf

Lenton TM, Held H, Kriegler E, Hall JW, Lucht W, Rahmstorf S, Schellnhuber HJ (2008) *Tipping elements in the earth's climate system*. Proceedings of National Academy of Science 105(6):1786–1793

Liekens, I., Broekx, S., Smeets, N., Staes, J., Van der Biest, K., & Schaafsma, M., De Nocker, L., Meire, P., Cerulus, T., (2013). *The ecosystem services valuation tool and its future developments*. Ecosystem Services, 249-262. doi: 10.1016/b978-0-12-419964-4.00019-6

Merriam, Dee. (2010). *Urban green infrastructure: A study of implementation strategies.*

Millennium Ecosystem Assessment. (2005). *Ecosystems and human well-being: synthesis*. Island Press, Washington, DC. Retrieved from http://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Müller, D. B., Liu, G., Løvik, A. N., Modaresi, R., Pauliuk, S., Steinhoff, F. S., & Brattebø, H.(2013). *Carbon emissions of infrastructure development*. Environmental Science & Technology, *47*(20), 11739-11746

National Academies of Sciences, Engineering, and Medicine. (2018). *Thriving on Our changing planet: A decadal strategy for earth observation from space*. Washington, DC: The National Academies Press

Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. (2015). *Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes*. Landscape and Urban Planning, *134*,127-138.

Nystro¨m, M. and Folke, C. (2001) *Spatial resilience of coral reefs*. Ecosystems, 4, 406–417.

Palomo, I., Felipe-Lucia, M., Bennett, E., Martín-López, B., & Pascual, U. (2016). *Disentangling the pathways and effects of ecosystem service co - production*. Ecosystem Services: From Biodiversity to Society, Part 2, 245-283. doi: 10.1016/bs.aecr.2015.09.003

Parker, D. (2009). *Urban heat island effects on estimates of observed climate change*. Wiley Interdisciplinary Reviews: Climate Change, 1(1), 123-133. doi: 10.1002/wcc.21

Roders, M., Straub, A., & Visscher, H. (2013). *Evaluation of climate change adaptation measures by Dutch housing associations*. Structural Survey, 31(4), 267–282.

Rotterdam, G. (2017). *Rotterdam duurzaam | 010duurzaam.nl*. Retrieved from https://www.010duurzamestad.nl/

Scholes, R., & Smart, K. (2013). *Carbon storage in terrestrial ecosystems*. Climate Vulnerability, 93-108. doi: 10.1016/b978-0-12-384703-4.00411-1

Seto, K. C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G. C., Dewar, D., & McMahon, J. (2014). *Human settlements, infrastructure and spatial planning. In: climate change 2014: Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sempergreen (2019). *Benefits of a green roof* - Retrieved from https://www.sempergreen.com/en/solutions/green-roofs/green-roof-benefits

Licheva, V. (2018). *The Dutch and innovation: Installing blue and green roofs in Amsterdam – DutchReview*. Retrieved from https://dutchreview.com/cities/amsterdam/the-dutch-and-innovation-installing-blue-and-green-roofs-in-amsterdam/

Technical Preservation Services, National Park Service. (2019). *Green roof benefits*. Retrieved from https://www.nps.gov/tps/sustainability/new-technology/green-roofs/benefits.htm

Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., & James,P. (2007). *Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review*. Landscape and Urban Planning, *81*(3), 167- 178.

UNFCCC (2015) *The Paris agreements. United Nations framework convention on climate change*. Retrieved from https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

Appendix I Interview Guide

I would like to introduce myself as Pravinraj Alagumannan Master's student of the Programme Environmental and Energy Management from the University of Twente. I am presently conducting research on "Ecosystem services and green infrastructure in cities" as my master's thesis. The objective of the study is to evaluate the possible impact and improvement of green infrastructure methods of De Dakdokters' in adapting to urban climate change in the Netherlands.

In this connection, the available published documents on the web sources have been reviewed. Further, in order to obtain additional information and your insights, a short meeting with you would be extremely valuable for the research.

In view of the above, I would be extremely obliged if you could confirm your consent. The meeting will be held on telephone or email (30-45 minutes), as per your convenience. It is possible to stop the interview at any point for your convenience.

Questions for University Experts

1. How do the identified ecological services (rainwater buffer, air purification, reduction of ambient temperature and noise, carbon sequestration, erosion protection) enable the adaptation to urban climate change?
2. What are the factors affecting the functions of green roofs?
3. What are the negative effects of having a green roof?
    a. Economic
    b. Ecological
    c. Socio-cultural
4. Are the green roofing methods sustainable to adapt to climate change? (Sustainable in this context is identified to mean lifespan of green roof and their benefits)
5. How do green roofs help in adding cultural values?

Questions for respondents from De Dakdokters Company

a) Economic aspects

1. What are the operating cost and maintenance costs of green roof, polder roof, roof garden, and roof park?
2. Do the roofs create monetary value, for example, reduction of expenditures or creation of income?
    - If yes, how is this value measured?
3. What is the expected payback period for a green roof, polder roof, roof garden, and roof park?
    - How is the payback period calculated?
4. Does the government provide subsidies or incentives for different types of green roofs?
    - If yes, what are the conditions?
    - If no, are subsidies and incentives needed for the diffusion of green roofs?
5. What value do they add to the building in terms of its price?

6. What value do they add to the building in terms of its energy use?
7. What value do they add to the building in terms of its life span?
8. Does having a green roof affect the structure of the building? If yes, how?
9. Does it incur the additional cost of construction?

b) Ecological benefits

For each of roof type, please highlight the extent to which it provides the mentioned ecological services by using “high”, “medium” and “low”

	Rainwater buffer	Air purification	Reduce Ambient Temperature	Reduce Ambient Noise	Increase Biodiversity	Increase solar panel efficiency	Extend the life span of roof	Sequester carbon	Erosion protection
Green Roof									
Roof Garden									
Roof Park									
Polder roof									

1 Please explain how the roof brings about the above-mentioned functions.

2 What are the factors affecting the functions of a green roof? Please explain how they affect.

3 Please explain how the above-identified services benefit

- the user,
- society,
- climate change.

1 What percentage of your clients create green roofing methods as

- recreational area,
- commercial purpose,
- improving appearance

2 How do they describe the changes, benefits, or experiences they have gained by using the roof?

- Changes:
- Benefits:
- Experience:

Appendix II Consent Form

Title of research: “Ecosystem services and green infrastructures in cities”

The purpose of this research project is to evaluate the possible impact and improvement of De Dakdokters green infrastructure methods in adapting to urban climate change in the Netherlands. This research is conducted by Pravinraj Alagumannan student at the University of Twente, Masters in Environment and Energy Management. You are invited to participate in this research because as a member of De Dakdokters / Expert in the relevant field, the research would appreciate knowing your view and perception regarding green infrastructure.

I declare to be informed about the nature, method, and purpose of the investigation. I voluntarily agree to take part in this study. I keep the right to terminate my participation in this study without giving a reason at any time.

My responses may be used solely for the purposes of this study. In its publications, they may (please tick one of the options):

O be cited with my name or function revealed

O be cited anonymously, thus without identifying the context

O only used as an information source

During the course of the interview, I keep the right to restrict the use of (some of) my answers further than indicated above.

Name participant:…………………………………………………………………………..

Date: ……………………….……… Signature participant: …………………………………

I declare to fully adhere to the above.

Name researcher:…………………………………………………………………..…………..

Date: …………………………….…… Signature researcher:……………………………….