GREEN ROOF AS AN ELEMENT OF GREEN INFRASTRUCTURE AND INFERENCES FOR IMPLEMENTATIONS IN TURKEY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

ÜNZİLE GÖÇ YENER

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
EARTH SYSTEM SCIENCE

SEPTEMBER 2021

Approval of the thesis:

GREEN ROOF AS AN ELEMENT OF GREEN INFRASTRUCTURE AND INFERENCES FOR IMPLEMENTATIONS IN TURKEY

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ABSTRACT

GREEN ROOF AS AN ELEMENT OF GREEN INFRASTRUCTURE AND INFERENCES FOR IMPLEMENTATIONS IN TURKEY

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September 2021, 152 pages

With the transformation of natural areas into impermeable surfaces such as roads and buildings, the effects of climate change have been observed more frequently in the last decades. Some examples are natural disasters such as extreme heat waves, floods and forest fires that have been observed worldwide. The concept of "green infrastructure", which is defined as a network of natural and semi-natural areas, provides the maintenance of these areas, and offers their benefits to people. Green infrastructure creates a livable environment by protecting ecosystems and maintaining biodiversity with its multi-functionality, connectivity and multi-scale features. Green roof is considered as a green infrastructure element. This study analyzes the concept of green roof, the benefits it provides, illustrates different practical cases across the world, and evaluates how green roof can effectively be incorporated to the green infrastructure, with regard to the approaches and principles implemented in different cases. Lastly, the study describes some practices in Turkey, and seeks some urban policy implications for more effective implementations.

Keywords: Green Roof, Green Infrastructure, Sustainability, Ecosystem Services

ÖZ

BIR YEŞİL ALTYAPI BİLEŞENİ OLARAK YEŞİL ÇATI VE TÜRKİYE’DEKİ UYGULAMALAR İÇİN ÇIKARIMLAR

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Ortak Tez Yöneticisi: Prof. Dr. İsmail Yücel

Eylül 2021, 152 sayfa

Doğal alanların yol, bina gibi geçirimsiz yüzeylere dönüşmesiyle birlikte iklim değişikliğinin etkileri son yıllarda daha sık gözlenmektedir. Dünya çapında gözlemlenen aşırı sıcak dalgaları, sel ve orman yangınları gibi doğal afetler iklim değişikliğinin etkilerindendir. Doğal ve yarı doğal alanlardan oluşan bir ağ olarak tanımlanan “yeşil altyapı” kavramı bu alanları sürdürülebilir şekilde devam ettirip faydalarını insanlara sunmaktadır. Yeşil altyapı, çok işlevliliği, bağlanabilirliği ve çok ölçekli özellikleri sayesinde ekosistemleri koruyarak ve biyoçeşitliliği sürdürerek yaşanabilir bir çevre yaratır. Yeşil çatı, bir yeşil altyapı unsuru olarak kabul edilmektedir. Bu çalışma yeşil çatı kavramını ve sağladığı faydaları analiz etmekte, dünya çapındaki farklı uygulama örneklerini göstermekte ve farklı durumlarda uygulanan yaklaşımlar ve ilkeler açısından yeşil çatının yeşil altyapıya nasıl etkin bir şekilde dâhil edilebileceğini değerlendirmektedir. Son olarak, çalışma Türkiye'deki bazı uygulamalardan bahsetmekte ve daha etkili uygulamalar için bazı kentsel politika çıkarımları yapmaktadır.

Anahtar Kelimeler: Yeşil Çatı, Yeşil Altyapı, Sürdürülebilirlik, Ekosistem Servisleri

To all women killed by violence

ACKNOWLEDGMENTS

First of all, I would like to give my biggest thanks to my supervisor Prof. Dr. Bahar Gedikli for her great support, encouragement and unlimited patience. I would also thank to my co-supervisor Prof. Dr. İsmail Yücel for his support and guidance. I also would like to thank to examining committee members Prof. Dr. Ela Babalık, Prof. Dr. Nilgül Karadeniz and Assist. Prof. Dr. Mehmet Koray Pekeriçli for their contributions and suggestions.

I owe special thanks to my dearest friend Zeynep Gür for her motivation, understanding and joy. She cheers me up from miles away every time I am out of mood. I also would like to thank Taylan Burak Nikbay for helping me focus on my thesis by undertaking most of the work at the office.

I gratefully thank to my mother Serpil Göç and my father Gürsel Göç not only providing me with financial and moral support so far but also their endless love and belief. My precious sister Melike Göç whom smile and innocence encouraged me to finish my thesis. My ugly sister Ezgi Göç also deserves huge thanks she was by me during my all hard moments. She calmed me down and made me laugh with clever jokes when I was nervous and cried. Also, two precious people to deserve special thanks. One is my aunt Fatma Pekmez who gave me a different perspective during the four years we lived together and encouraged me to do master's degree. Secondly, every time my grandfather called, he never let go of the question of when will your thesis completed. No one could be more involved than him.

Last but not the least, my deepest gratitude goes to my husband Ümit Yener for his patience, wisdom and love. I would like to thank him for listening to my complaints about my thesis every single day for 4 years, for taking the responsibilities for care and housework attributed to women in the society and encouraging me to complete my thesis. I would not have been complete this thesis without his logical thoughts, delicious meals, and endless love.

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CHAPTER 1

INTRODUCTION

"We don't inherit the earth from our ancestors, we borrow it from our children."

Native American proverb

1.1 Problem Definition

With the rapid population growth all over the world, increasing amount of impermeable surfaces, and decreasing green areas, extreme climatic events are observed more frequently such as heatwaves and decreasing humidity (Vijayaraghavan, 2016, 741). Besir and Cuce (2018, 915) state that most of the world population lives in cities and it is expected that the population in urban areas will increase day by day. United Nations explains the population growth expectations as follows: "*55% of the world's population lives in urban areas in 2018, a proportion that is expected to increase to 68% by 2050"* (United Nations, 2020). Berardi et al. point out that buildings are responsible for about 40% of energy use and 33% of greenhouse gas emissions (GHG) all over the world (Berardi et al, 2014, 412).

The effects of climate change have been seen more often due to reasons such as increase in temperature and emissions, and decrease in humidity. In the summer of year 2021, the break of temperature record with 49°C in Canada, floods that damaged Germany and Belgium, forest fires in Turkey and Greece reveal the serious dimensions of climate change (BBC, 2021; BBC, 2021; The Guardian, 2021).

It is necessary to decrease the level of carbon emissions and increase the permeable surfaces to mitigate the effects of climate change and achieve a sustainable future with the help of green spaces. The sustainable development goals (SDGs), adopted by the United Nations in 2015, represent a universal call to end poverty, protect the planet and establish equality and peace by 2030. SDG 11, named “sustainable cities and communities”, aims to improve sustainable urban planning, while SDG 13, named “climate action”, is for mitigation and adaptation of drastic effects of climate change (United Nations, 2020).

Achieving sustainable cities is a complex process that includes environmental, social, and economic fields. Green infrastructure is accepted as an appropriate tool that connects and conserves ecosystems and procures ecosystem services to achieve sustainable development in cities (Ramyar et al, 2020, 2). Meanwhile, green roof, which is an element of green infrastructure, is an effective tool to utilize idle rooftops so as to contribute to the improvement of ecosystem services.

1.2 Aim and Scope of the Study

This thesis explores the green roof implementations as an element of green infrastructure. It aims at carrying out this analysis at different spatial scales (i.e. at building, district/negihborhood and settlement scales), and making inferences for practices in Turkey. The literature review, therefore, basically focuses on two main concepts, which are “green infrastructure” and “green roof”.

Firstly, the principles and benefits of green infrastructure in general, and urban green infrastructure in particular are explained so as to understand “how urban green infrastructure provides ecosystem services”. Literature highlights basic principles of green infrastructure as connectivity and multi-functionality, which can be performed with a multi-scale approach. Thus, green infrastructure implementations at different scales are elaborated.

Secondly, the origin, layers, and benefits of the green roof are explained to clarify how it is an element of green infrastructure. This analysis is supported with some practical examples across the world and Turkey.

Following that, different policy-making, planning, and legislative tools are examined, which are applied for green roof implementations in different countries.

It is important to understand how the green roof is integrated into a holistic approach, i.e. as a component of the green infrastructure at different scales.

This section is followed by the elaboration of green roof implementations in Turkey, seeking answers to the following questions: Are green roof implementations in Turkey part of a holistic approach? Do green roof implementations provide two main principles (connectivity ve multifunctionality) of green infrastructure? What tools are used in these implementations? What should be done to develop the green roof concept? The study concludes with an overall evaluation of the green roof concept with some urban policy implications.

1.3 Structure of the Study

This thesis consists of six chapters including the introduction and the conclusion. The introduction part states the problem definition, aim of the study and draws a general overview.

Chapter 2 focuses on the "green infrastructure" concept. Firstly, two basic principles of green infrastructure, which are multi-functionality and connectivity,are explained. These are characteristics that distinguish green infrastructure from green space. Second the benefits of green infrastructure are elaborated with reference to some practical examples across the world. Lastly, examples of green infrastructure at different spatial scales will be discussed.

Chapter 3 focuses on the green roof concept, its layers, and implementation process. This chapter mainly emphasizes the importance of green roofs as an element of urban green infrastructure. It also elaborates the history of the green roof that goes back to the Hanging Gardens of Babylon. Lastly, it presents different examples of green roof implementations from the world and Turkey.

Chapter 4 puts forward the methods that are used in green roof implementations in different countries. The examples mentioned in this chapter are discussed at two different spatial scales, namely city and neighborhood scales. Green roof is not only implemented at the building scale, but also at wider spatial scales by including it in different urban policies.

Chapter 5 focuses on the green roof implementations in Turkey. The results obtained from the previous chapter are compared with the examples of green roof implementations in Turkey. This chapter evaluates the achievements and inadequateness of implementations in Turkey, and looks for answers with regard to literature review and successful examples.

The last chapter summarizes the findings of the thesis, discussions, and recommendations for further researches.

CHAPTER 2

GREEN INFRASTRUCTURE IN URBAN AREAS

"We can never have enough of nature"

Henry David Thoreau

2.1 Definition of Green Infrastructure

After the industrial revolution, the population in cities increased because of the migrations from rural to urban areas (Sandström, 2002, 373). Hence, the uncontrolled growth of cities led to the loss and degradation of ecosystems and the urban green space as well as negative health effects on humans (Tzoulas et al, 2007, 167). These worldwide developments triggered nature conservation efforts.

In the second half of the 1800s, the American naturalist and philosopher Henry David Thoreau wrote a book about the importance of conserving nature, which became a milestone at the beginning of raising awareness about conservation (Benedict and McMahon, 2012, 25). He lived in the woods for years and believed that the relentless exploitation of resources such as hunting for sport and intensive lumbering threaten the existence of nature (Garand, 1970, 73). He states his thoughts related to urban design in the following words: "Every town should have a park, or rather a primitive forest, of five hundred or a thousand acres, either in one body or several, where a stick should never be cut for fuel, nor for the navy, nor to make wagons, but stand and decay for higher uses — a common possession forever, for instruction and recreation" (Benedict and McMahon, 2012, 25).

Frederick Law Olmsted who agreed with Thoreau defined urban as a biologically artificial environments which is harmful for people's both physical and mental health (Benedict and McMahon, 2012, 26). Olmsted is known the pioneer of landscape ecology, shaped the American park concept with his parks that were designed for American cities (Austin, 2014, 9). His works are considered to be the first examples of the idea of linking social opportunities, and ecological functions of green space (Mell, 2008, 71). He says that "No single park, no matter how large and how well designed, would provide the citizens with the beneficial influences of nature" (Benedict and McMahon, 2012, 26). He designed the Emerald Necklace Figure 2.1 and Figure 2.2), which is composed of a chain of open spaces and a network of corridors over 450 ha area in Boston (Austin, 2014, 9). Even though it was designed as a precaution for floods from the Charles River, it also provides ecological (flood management), social (health) and economic (tourism) benefits for both habitants and visitors (Mell, 2008, 71).

Figure 2.1 Aerial view of Emerald Necklace

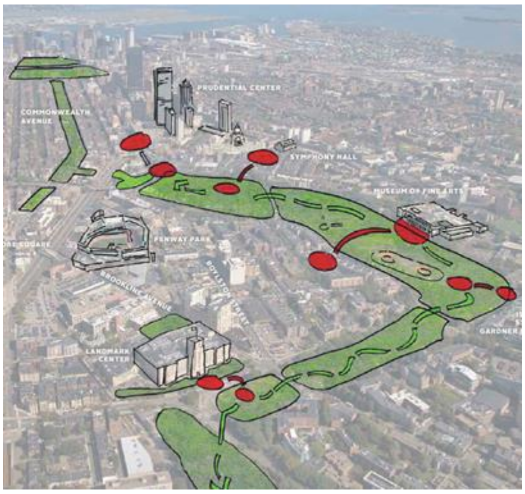

Figure 2.2 Conceptual drawing of Emerald Necklace

(http://www.bostonplans.org/getattachment/4eb46c0a-b353-40ae-b887-596a2878a316)
[Accessed: 24.10.2020]

Today, most of green infrastructure researchers still discuss that Olmsted’s Emerald Necklace and other works encouraged the integration of function and form which result in multi-functionality of landscape. These discussions have generated the fundamentals of green infrastructure strategy (Little, 1990; Fábos, 2004; Williamson, 2003 cited in Mell, 2008, 71).

The expression of green infrastructure was first used in a report about land conservation strategies in Florida (Benedict and McMahon, 2012, 35; Firehock and Walker, 2015, 10). Firehock and Walker (2015, 10) state that *"combining the words 'green' and 'infrastructure' was intended to reflect the notion that natural systems are equally, if not more, important components of our 'infrastructure' and should be included in the planning process."*

Green infrastructure (GI) is an approach which promotes economic, social and environmental benefits (Demuzere et al, 2014, 108; Tzoulas et al, 2007, 173). It helps people to understand the value of benefits that nature provides them, maintain them sustainably and revitalize investments that are created. In other words, "green infrastructure is a planned network of high quality natural and semi-natural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings" (European Commission, 2013, 7).

According to the Environmental Protection Agency (2015, 1) in the United States, green infrastructure is a resilient and cost-effective means not only to manage the quantity of stormwater but also to enhance the quality of water by ameliorating the hydrological function of the urban areas.

Regardless of the definition, green infrastructure is a nature-based solution that creates a healthier, livable environment through the reflection of nature within the urban areas (Austin, 2014, 4). Hence, it reduces the adverse impacts of climate change by providing numerous benefits such as managing stormwater runoff, filtering air and water pollutants, and absorbing atmospheric CO_2, mitigating the effects of the urban heat island (Demuzere et al, 2014, 108; Lovell and Taylor, 2013).

Green infrastructure has some principles which are integration, social inclusion, connectivity, and multi-functionality. Integration refers to the incorporation of green, blue and grey infrastructure. It provides physical and functional synergy among green spaces and blue infrastructures such as water bodies, and grey infrastructures such as settlements and wastewater systems (Karadeniz and Taşkın, 2020, 37; Pauleit et al, 2011, 274). Social and ecological inclusion is related to the heterogeneous structure. Green infrastructure planning starts at the regional scale, where ecological inclusion principle should be met. Green infrastructure also includes the principle of social integration which involve everyone living in urban and rural areas, including disadvantaged groups such as elderly and disabled people (Karadeniz and Taşkın, 2020).

The most important characteristics that distinguish the concept of "green infrastructure" from the concept of "green space" are connectivity and multi-functionality (Mell, 2008, 70). The term connectivity implies that each green element has interacted with not only other green elements, but also other built systems (Ajuntament de Barcelona, 2017, 18). Figure 2.3 shows that the difference between connected green spaces and fragmented ones.

Figure 2.3 Fragmented green spaces vs. hierarchically connected green spaces network

(https://worldlandscapearchitect.com/petrzalka-masterplan-bratislava-slovakia-markoplacemakers-gutgut-labak/#.X7kU-GgzbIU) [Accessed: 20.11.2020]

Meanwhile, multi-functionality focuses on multiple goals by providing environmental, social and economic benefits such as improving water quality, offering people education and recreation opportunities, and providing energy efficiency to buildings (Ahern, 2007, 268). In other words, the main difference between "green space" and "green infrastructure" can be explained that green space is any vegetated area which is seen as self-sustaining such as recreation sites and isolated parks, while green infrastructure is a functioning combination of green spaces and natural systems that must be protected and managed for its ecological benefits (Benedict and McMahon, 2012, 2-3).

Green infrastructure can be practiced at all spatial scales such as an individual parcel, the neighborhood and the city (Benedict and McMahon, 2012, 14; Hansen and Pauleit, 2014, 517). For instance, forests, floodplains, green belts, and agricultural lands can contribute to green infrastructure at city-scale while allotment gardens and cemeteries can be examples at the neighborhood scale (Ajuntament de Barcelona, 2017, 7; European Commission, 2013, 8-9) Green roofs and rain gardens, which are installed in a single building and parcel respectively, can represent the examples in the individual parcel (Firehock and Walker, 2015, 10). Ahern (2007, 270) states that *"the multi-scaled approach involves assessment and planning of spatial configuration of landscape patterns and ecological processes at multiple scales, and how these patterns and processes interact"*. Because of these particular patterns and processes, the use of the same components of green infrastructure at different scales can give different outcomes (Basnou et al, 2015, 2). For instance, when the CO_2 reduction, a benefit provided by green infrastructure, was studied at different spatial scales, it was found that the effect was less on the individual parcel than the neighborhood and city scales. This is why a larger volume of vegetation removes a more significant amount of CO2 (Demuzere et al, 2014, 111).

2.2 Benefits of Green Infrastructure

Green infrastructure can promote landscape sustainability by establishing a wide range of ecosystem services (Zhang and Ramírez, 2019, 59). The generation of benefits are provided by ecosystem services in urban areas (Chan et al, 2012 cited in Demuzere, et al, 2014, 108). These services provided by green infrastructure depend on many considerations such as location, geographical conditions, and socio-demographic factors of the city (Ramyar et al, 2020).

Also, any example of green infrastructure can ensure different ecosystem services at different scales thanks to multi-scale and multi-functionality nature (Demuzere et al, 2014, 108; Ramyar et al, 2020, 2). For example, a floodplain prevents the flooding events by regulating water is an ecosystem service. From a different point of view, the same floodplain provides recreation facilities to people which is a social benefit (Demuzere et al, 2014, 108).

The benefits of green infrastructure can be categorized as three as environmental, social and economic ones.

2.2.1 Environmental Benefits

Green infrastructure aims to ameliorate nature's ability and contribute to the creation of healthier environments and protect the urban biodiversity (European Commission, 2013, 7; Zhang and Ramírez, 2019, 60). Green infrastructure planning is a very convenient tool for urban planning because urban areas are composed of a dynamic interaction of social and ecological systems (Hansen and Pauleit, 2014, 517). Ecosystem services flow to cities through a green infrastructure. This flow emphasizes daily processes and life-support functions of ecosystems that are defined as environmental benefits (Basnou et al, 2015, 3). These are carbon storage and sequestration, air and water purification, climate regulation, moderation of extreme events, conservation of biodiversity, mitigation of urban heat island and noise abatement (Pakzad et al, 2015, 2).

2.2.1.1 Carbon Storage and Sequestration

Elements of green infrastructure such as trees and different plant types have important roles in decreasing the amount of atmospheric CO_2 through carbon storage and sequestration (Austin, 2014, 63; European Commission, 2013, 6; Nowak, 2001 cited in Pakzad et al, 2015, 1; Wang et al, 2014, 93). Green infrastructure provides carbon storage with biomass both in the soil and the plant as well as carbon sequestration with the help of photosynthesis (Pakzad et al, 2015, 1). However, their absorption level depends on the particular characteristics of plant and soil types such as drought tolerance of the plant, size of the leaf areas, and soil pH and quality (Ramyar et al, 2020, 5).

Especially forests that are natural carbon sink areas capture over half of the atmospheric CO_2 thanks to these characteristics (IPCC, 2005). Austin (2014, 63) points out that a set of 100 large mature trees remove 13 tons of CO_2 from the atmosphere every year. For this reason, reforestation can be the best alternative for carbon sequestration because it is relatively inexpensive and gives measurable outcomes (Benedict and McMahon, 2012, 62).

In a survey carried out in Beijing, China, it was calculated with the help of satellite images and modeling studies that almost 0.2 million tons of CO_2 were absorbed by the 2.4 million trees in the center of the city (Yang et al, 2005, 65).

Although forests have the largest impact, other green areas, too, significantly affect the local concentration of CO_2 (Samson et al, 2017, 135). To illustrate, it is estimated that a green roof can reduce the rate of CO_2 concentration of the surrounding areas up to 2% on a sunny day although the precise outcome depends on the size of the roof or plant types on the roof (Vijayaraghavan, 2016, 744).

2.2.1.2 Air Purification

Another environmental benefit of green infrastructure is air purification. Because of the rapid industrialization and urbanization of the cities, human activities like transportation and energy production are increased that lead to the dust and gaseous air pollutants (Bolund and Hunhammar, 1999, 295). These air pollutants such as carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO_2), ozone (O_3), and especially particulate matter (PM_{10}) not only decrease the quality of air, but also can pose serious health problems on both human and environment (Austin, 2014, 19; Wang et al, 2014, 92). Depending on the alteration of size and concentration of the pollutants, adverse impacts on humans and the environment can be changed (Wang et al, 2014, 92).

Vegetation, especially forests and trees, has the ability to absorb hazardous air pollutants from the atmosphere (Environmental Protection Agency, 2015, 4; Yang et al, 2005, 65). For example, a study conducted in Beijing (China) indicates that approximately 30,180 hectares of forest area can remove around 1,261 tons of air pollutants which consist of NO_2, O_3, SO_2, and PM_{10} from the atmosphere (Yang et al, 2005, 74).

Another study revealed that 3,700 m^2 green roofs can remove about 725 kg particulate matter, which is one of the major pollutants in urban areas, from the atmosphere each year (Gill et al, 2007 cited in Molla, 2015, 97).

Even though vegetation helps to enhance significantly, the removal of particles depends on some factors such as forms, shapes of the leaves, and canopies of the trees. In addition to the characteristics of the plant, the concentration and size of particles are important drivers for the removal of pollutants (Samson et al, 2017, 21). Beckett et al. (2000 cited in Yang et al, 2005, 65) point out that evergreen trees are more efficient in absorbing air pollutants because they stay green a longer time than deciduous ones.

2.2.1.3 Stormwater Management

Increasing levels of impervious surfaces are directly related to an increase in the amount of stormwater runoff, flow rate, and flooding events (Armson et al, 2013 cited in Vilhar, 2017, 41; American Rivers et al, 2012, 21). Pauleit and Duhme (2000 cited in Vilhar, 2017, 43) state that if the built-up areas increase by 10%, the rainfall absorption rate of per unit land area reduces by an average of 5% in Munich.

One of the most important services provided by green infrastructure is water absorption and flood regulation because the natural elements such as soil and vegetation soak up some amount of the precipitation (Sanders 1986 cited in Vilhar, 2017, 41). In the case of a reduction of these elements, the rest of the precipitation accumulates over the impervious surfaces and turns even into the flood.

Floods not only damage the environment such as bank erosion (American Rivers et al, 2012, 22), but also causes in both physical and psychological problems in human health (Gill et al, 2007, 116). However, green infrastructure manages water quantity by contributing to hydrological processes through its capabilities such as evapotranspiration, photosynthesis and water infiltration (Environmental Protection Agency, 2015, 1). Street trees, rain gardens and bio-swales are the most efficient green infrastructure elements to improve stormwater management (Norton et al, 2015, 134).

City of Melbourne started to implement green infrastructure projects about water management because precipitation levels declined and the frequency of summer droughts is increased. The ultimate goal of these projects is the reduction of irrigation demand for tap water through the regulation of stormwater runoff. For instance, harvesting stormwater was used for irrigation in agriculture or flush the toilets (Li and Bergen, 2018, 129).

In Malmö, an open stormwater system and almost 10,000 m^2 green roofs were constructed as a part of the Ekostaden Augustenborg initiative which is a regeneration initiative to make the Augustenborg neighborhood more sustainable. It was determined that the total annual stormwater runoff volume decreased by 20% in comparison with the conventional system based on the result of the modeling studies (Kazmierczak and Carter, 2010, 93). Figure 2.4 and 2.5 shows green infrastructure elements in Augustenborg neighborhood.

Figure 2.4 Stormwater canal at the Eco City Augustenborg

(Kazmierczak and Carter, 2010)

Figure 2.5 Pond at the Eco City Augustenborg

(Kazmierczak and Carter, 2010)

2.2.1.4 Water Purification

One of the major factors, which leads to the raise of water pollution level, is the increased urbanization and excessive amount of impervious surface in the cities (National Research Council, 2009 cited in American Rivers et al, 2012). The stormwater picks up and carries a load of nutrients, heavy metals, organic pollutants, and harmful substances from the impervious surfaces such as pavements and roads until it reaches a treatment system. (Pape et al, 2012 cited in Vilhar, 2017, 43). Like air pollutants, water pollutants have also negative impacts on both human health and the environment.

One of the most important purposes of the green infrastructure is to reduce pollutant loads, sedimentation, and stream erosion (Environmental Protection Agency, 2015, 1) with the help of vegetation, tree roots and leaf litter (Vilhar, 2017, 43). In other words, vegetation ensures the purification of water by removing the pollutants from water through transpiration (Austin, 2014, 47).

Various green infrastructure elements, which are integrated tree trench system, stormwater planters, rain gardens, and infiltration trenches, were constructed within the Green Line Project to reduce pollution in the Mississippi River in Minnesota. It was estimated that green infrastructures remove more than 60% of total phosphorus in the stormwater runoff annually (Capitol Region Watershed District, 2012, 29).

The City of Melbourne constructed "*Trin Warren Tam-Boore Wetland*" (Figure 2.6) in 2006 so that the city can use the stormwater for irrigation purposes after it can be purified. The system not only meets 160 megaliters of the city's irrigation needs, but also reduces about 77% of total suspended solids and 45% of total nitrogen. (State Government of Victoria, 2015).

Figure 2.6 Trin Warren Tam-Boore Wetland

(http://urbanwater.melbourne.vic.gov.au/industry/treatment-types/constructed-wetlands/)
[Accessed: 13.11.2020]

2.2.1.5 Mitigation of Urban Heat Island Effect

Because of the high energy use of the cities and abundance of impervious materials like roads, pavements, and buildings, urban areas have a higher surface temperature than rural ones. This phenomenon is named as urban heat island (Santamouris, 2014, 682; Osmond and Irger, 2016, 38). These materials tend to trap and store heat during the daytime. At night they release the heat slowly (Lin et al, 2016, 1; Norton et al, 2015, 128; Wang et al, 2014, 90).

However, any element of green infrastructure reduces the urban heat island by absorbing CO_2. In addition to the ability of CO_2 absorption, green infrastructure can reduce the urban heat island effect through evapotranspiration and shading (Wang et al, 2014, 90; Hiemstra et al, 2017, 11). Figure 2.7 shows the temperature differences between non-shaded and shaded areas. Particularly, trees are the best means to reduce the impacts of urban heat island effect with dense canopy cover and high capability of evapotranspiration. Green grasses are more effective to decrease the surface temperature than bare soil and concrete surfaces but not as much as trees (Lin et al, 2016, 2).

Coutts and Harris (2013 cited in Norton et al, 2015, 128) assert that urban surface temperature will decrease by approximately 1% if the vegetation cover is increased by 10%. With the canopy of vegetation, the average ambient air temperature is estimated to decrease between 0.9°C and 2°C (Wang et al, 2014, 91).

According to a study carried out in Greater Manchester (Figure 2.8), the maximum surface temperature of woodlands is 18.4°C while the city center is 31.2°C. As a consequence, the city center is 12.8°C warmer than the city centers because of the impermeable land uses (Gill et al, 2007, 121-122).

Figure 2.7 Surface temperature differences in Northern Israel

(Hiemstra et al, 2017)

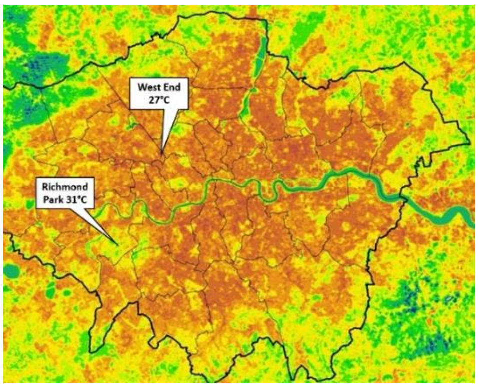

Figure 2.8 London's surface temperature on the 26th July 2011

(ARUP, 2014) [Accessed: 13.11.2020]

2.2.1.6 Climate Regulation

Reforestation, afforestation, and land use facilities are strongly related to carbon exchange between the atmosphere and biosphere which is a significant consideration in climate regulation (Pakzad et al, 2015, 1).

Green infrastructure has the ability to regulate climate by providing a cooling effect. Evapotranspiration and reduction of surface temperature through shading are the most important considerations which contribute to the cooling effect (Samson et al, 2017, 133). In addition to these characteristics, green infrastructure supports climate regulation by providing the sequestration and storage of carbon (Austin, 2014, 63). Especially trees have enormous effects to moderate the climate and mitigate the surface temperature by providing insulation, shading, and wing barrier mechanisms (Austin, 2014, 45; Forest Research, 2010 cited in Molla, 2015, 97).

According to Bolund and Hunhammar (1999, 296), a single large tree can transpire 450 liters of water per day which means consumption of 1,000 MJ of heat energy for evaporation. As a result, trees are one of the most important elements to reduce the surface temperatures of the city.

In the study of Şimşek and Şengezer (2012, 124-125), which was conducted for Istanbul, the temperature of an area with dense vegetation was estimated as 38.482°C while the expected temperature of the area with sparse vegetation was 42.723°C. As a result of these analyzes, it was found that change in vegetation cover affects the urban climate by about 4°C.

2.2.1.7 Conservation of Biodiversity

Biodiversity is a means to determine whether ecosystems are healthy or not (Firehock and Walker, 2015, 49). Biodiversity loss is mostly caused by habitat fragmentation and edge effect because such fragmented habitats are more vulnerable to external pressures such as extreme temperatures (European Commission, 2013, 5). Especially the highways, railroads and large built-up areas around the cities create barrier effects for the migration and breeding of many species (Bolund and Hunhammar, 1999, 300).

However, green infrastructure ameliorates the integrity of habitat systems and development of ecological networks by easing adverse effects of habitat fragmentation and edge effects (Tzoulas et al, 2007, 170).

A sustainable urban drainage system was implemented within the scope of the Ekostaden Augustenborg initiative which was performed between 1998 and 2002. This system includes green infrastructures such as ditches, retention ponds, green roofs, and green spaces. Biodiversity in the area increased by 50% at the end of the project. Green roofs host many birds and insects while the open stormwater system became one of the attractive spots for local plants and wildlife (Kazmierczak and Carter, 2010, 94).

2.2.1.8 Noise Abatement

Urban areas may be a harsh environment for residents because of noise pollution which is generally originated from a high volume of traffic and industrial facilities (Austin, 2014, 30). Noise exposure leads to some health problems like hearing impairment, sleep disturbances, and hypertension (Wang et al, 2014, 94). Green infrastructure, especially forests, is a tool to ease these adverse effects by masking the noise (Pinho et al, 2017, 68). In fact, plants mitigate the sound waves with their branches and leaves by absorbing and dispersing (Ramyar et al, 2020). Ow and Ghosh (2017, 15) state that "*On average, vegetative barriers (moderate to dense) were able to reduce traffic noise by 9–11 dB*". The amount of reduction depends on the vegetation types, the intensity of vegetation, and distance from the source (Ramyar et al, 2020).

Kragh (1981 cited in Ow and Ghosh, 2017, 19) studied on a conifer belt with 3 m deep, and observed noise abatement by 3-5 dB. Another study conducted by Van

Renterghem et al. (2012 cited in Wang et al, 2014, 94) found that the green roofs and walls have the ability of noise reduction up to 7.5 dB.

2.2.2 Social Benefits

Green infrastructure can also serve many socio-cultural and recreational values to both residents and visitors (American Rivers, 2012, 8). There are many proven benefits of natural elements in urban areas to material and spiritual values of human society that are associated with human well-being and comfort, particularly, the physical and mental health of the human (Lin et al, 2016, 9).

All of the benefits which are related to the human being are named as social benefits that vary from health issues to aesthetic concerns. When social benefits are compared to the environmental ones, it can be seen that environmental benefits are more tangible and quantifiable than the social ones. In other words, when an element of green infrastructure is implemented, temperature decrease or moderation of extreme events can be measured anywise. However, social benefits depend on the perceptions and pleasure of the people.

2.2.2.1 Recreation

Green infrastructure increases and enhances green spaces for a recreational area which offers people to rest and play (American Rivers, 2012, 28; Bolund and Hunhammar, 1999, 298). Recreational areas have been the main purpose of the green space design for many years in traditional urban planning (Sandström, 2002, 375). According to a study which was conducted in 7 different Swedish cities in 2002, people’s expectation about the high quality of life is limited to access to green infrastructure for recreation in their nearby environment (Sandström, 2002, 380).

In fact, recreation is just one of the purposes of green infrastructure which emphasizes ecologically important hubs, not an ultimate goal (Benedict and

McMahon, 2012). In contrast to the traditional understanding, green infrastructure is defined as a multifunctional planning and conservation tool in modern urban planning approaches (Austin, 2014, 5).

Although parks are the prominent component of the recreational green infrastructure, forests, trees along streams and streets, and green roofs provide recreational opportunities such as biking, walking and bird-watching (O'Brien et al, 2017, 190). In addition to these physical opportunities, it can facilitate improving the social cohesion of the community or neighborhood with respect to the scale of the area. According to a study carried out in Nigeria in 2013, if a park is designed and maintained successfully, it can connect people of different ethnic backgrounds and ages (Okunlola, 2013 cited in Molla, 2015, 92).

2.2.2.2 Health and Well-being

Green infrastructure has a significant role to ameliorate human's physical and psychological health, and well-being (European Commission, 2013, 6).

First of all, green infrastructure can be defined as a trigger for people to begin physical activities (Austin, 2014, 19). Kaczynski and Henderson (2007 cited in Bell et al, 2008, 25) mention that green spaces encourage people to do physical activities so they have a healthier profile, that is, there is a positive correlation between living closer to the green areas and increased physical activity. Decrease in the level of obesity, regulation of the blood pressure, and enhancement of the cardiovascular health are the major health benefits provided by increased physical activities through green infrastructure (Austin, 2014, 22).

In other respects, green infrastructure offers better air quality by emitting pollutants, toxics, and harmful chemicals suspended in the air (Ramyar et al, 2020, 3). Thus, people who have respiratory illnesses and asthma are positively influenced by the occasions of green infrastructure (Molla, 2015, 91; Benedict and McMahon, 2012, 69).

It is calculated that 700 cases of respiratory diseases were avoided annually through the 16,390 hectares green infrastructures which were implemented to prevent sewage overflows in the city of Philadelphia (American Rivers, 2012, 32).

Secondly, green infrastructure also affects psychological health positively (Pinho et al, 2017, 70; Bolund and Hunhammar, 1999, 298) Not only being in the green infrastructure, but also viewing them helps people to fight with stress and anxiety. According to a study carried out in hospitals in 2001, it was observed that patients whose rooms were viewing the green spaces recovered faster and took less care after any surgery (Wang et al, 2014, 94).

2.2.2.3 Education

Green infrastructure also serves people's education about the environment such as ecosystems, habitats, and species (Bell et al, 2008, 10; Environmental Protection Agency, 2015, 4). People use green infrastructure, particularly urban forests, as a learning and teaching area where nature and natural processes take place (O'Brien et al, 2017, 157). For example, a street tree teaches people, which bird species live in there. Likewise, a wetland can teaches people the aquatic ecosystems and native species such as birds, fishes, and aquatic plants. As people learn about ecosystems, habitats, and species, conservation efforts grow (O'Brien et al, 2017, 157).

Dört Koldan Doğa Project is supported by Tubitak in Ankara, which aims to create awareness about some types of ecosystems and sustainability in the METU Campus, which is spread over an area of 4,500 hectares. After an explanatory presentation is made to the participants, walks are organized to ecosystems such as steppe and lake (Figure 2.9). Hence, participants learn nature by seeing and touching (Gaia Dergi, 2018). By this means, people focus on practically-oriented learning instead of theoretical knowledge (Dearborn and Kark, 2010 cited in Demuzere et al, 2014, 111).

Figure 2.9 Trip to Yalıncak Lake in METU Campus within Dört Koldan Doğa Project

Personal Archive

The Big Butterfly Count is a nationwide survey which are conducted by Butterfly Conservation in England. The project aims not only to protect threatened with extinction butterflies but also understand the impacts of climate change on wildlife. Also, citizens learn to identify different butterflies and moths by counting them. In 2019 more than 113,500 citizens and scientists participated while 116,009 butterflies and moths are recorded (Butterfly Conservation, n.d.). Figure 2.10 and 2.11 show some moments from the Big Butterfly Count.

Figure 2.10 A team counting butterflies

Personal Archive

Figure 2.11 Red Admiral Butterfly

Personal Archive

2.2.3 Economic Benefits

2.2.3.1 Direct Economic Benefits

Economic values can be included in the ecosystem services which is a flow between ecosystem and human well-being (Chan et al, 2012 cited in Basnou et al, 2015, 3). There are some direct effects on both local and regional economy such as improved tourism, new job opportunities, and energy savings (Benedict and McMahon, 2012, 72-74). In addition to the direct benefits, green infrastructure offers some indirect benefits (Wang et al, 2014, 89). Although it is quite difficult to calculate the economic benefits of green infrastructure, some studies have attempted to improve various methods (Benedict and McMahon, 2012, 72).

2.2.3.1.1 Recreation and Tourism Spending

Recreation and tourism incomes constitute the majority of the total economic benefits (European Commission, 2013, 15). Generally, green spaces have the ability to attract tourists who want to benefit from the outdoor recreation such as fishing, camping. These recreation facilities contribute more returns to the economy through the purchase or lease of different types of equipment. On the contrary, some amenities do not require too much equipment such as hiking and bird watching (Firehock and Walker, 2015, 110). All of these activities that are related to natural ecosystems attract people to green and increase the level of the economic welfare of the country (Austin, 2014, 82).

Also, the tourist expenses cover lots of facilities such as hotel accommodation, nightlife, shopping, and restaurants (Firehock and Walker, 2015, 28). Bracken and Frio Caves in Austin (Texas) host one of the largest bat colony in the world. About 1.5 million free-tailed bats that live and breed in these caves that provides education as well as foster tourism. 100,000 tourists visit the city of Austin each year to watch the bats and learn their ecology (Figure 2.12). A local group of professionalists enable people to learn the ecology of bats and the benefits that they provide (Austin, 2014, 84).

Moreover, approximately 3,454 hectare of Charles River Basin in Massachusetts (Figure 2.13) provides $31 million in recreation value through activities like fishing and hunting (Benedict and McMahon, 2012, 70).

Figure 2.12 Bracken Cave in Austin
(https://tpwmagazine.com/archive/2019/oct/wanderlist/ [Accessed: 09.05.2021]

Figure 2.13 A rowing team in Charles River
(https://www.bostonusa.com/events/special-events/head-of-the-charles/) [Accessed: 13.11.2020]

2.2.3.1.2 New Job Opportunities

Another major economic benefit of green infrastructure is the creation of new job opportunities (European Commission, 2013, 6). All types of green infrastructure from recreation areas to forestry provide new job opportunities for people during both construction and maintenance periods (MMSD, 2010 cited in Molla, 2015). Recreation activities such as camping and bird watching support 3,466 jobs while roughly 4,450 jobs are supported by the fishing industry in West Virginia (Benedict and McMahon, 2012, 72).

Meanwhile, forest and agriculture facilities offer more than 357,000 jobs while the total annual revenue of them is about $82.5 billion in Virginia (Firehock and Walker, 2015, 109).

“Gelecek Turizmde” project from Isparta (Turkey) was implemented to increase the share of the lavender in the local economy. Some lavender products are produced in the village such as ice cream, jam, soap, and cologne by the local community. While 20,000 tourists visited the village in the summer of 2016, this number is 190,000 in the summer of 2018. Therefore, the income of the lavender is increased through the participation of local people to economic production (T.C. Kültür ve Turizm Bakanlığı, n.d.). Figure 2.14 belongs to a local woman who deals with the lavender in Isparta within the project of Gelecek Turizmde.

Figure 2.14 A local woman deals with lavender in Isparta

(https://www.tr.undp.org/content/turkey/tr/home/presscenter/articles/2018/07/bu-yaz-tatilde-nereye-gidiyorsunuz-.html)
[Accessed: 13.11.2020]

2.2.3.1.3 Energy Saving

One of the most important benefits of green infrastructure is reducing the consumption of energy by cooling the air temperature and providing insulation to nearby buildings (Firehock and Walker, 2015, 19). In other words, buildings which are located near green infrastructures such as the trees or vegetation consume less energy in both winter and summer months than the ones which are not located (Lin et al, 2016). As a result of reducing energy consumption, both energy costs and CO_2 emissions are reduced (Wang et al, 2014, 89; Austin, 2014, 78).

Not only trees in urban forests or woodlands, but also tree-lined streets, parks, and streams provide crucial ecosystem services to urban populations. (Hiemstra et al, 2017, 14). A study conducted in Canada pointed out that just a single tree can save from $10 to $60 by providing cooling and heating advancements (Akbari and Taha, 1992 cited in Wang et al, 2014, 95).

Particularly, green roofs and walls are more efficient in lowering the consumption of energy of buildings than the conventional ones (Austin, 2014, 182). EPA (2007 cited in Austin, 2014, 182) stated that a green roof can help to save energy costs from 15% to 25%. Obendorfer's study (2007 cited in Molla, 2015, 94) showed that approximately 1000 m^2 green roof saves $400 in heating activities while $250 in cooling activities.

2.2.3.2 Indirect Economic Benefits

Indirect benefits of ecosystem services of green infrastructure have also monetary value that can be measured through different types of valuation methods. These valuation methods can be categorized as avoided/replacement cost method, contingent valuation, and hedonic pricing (Wang et al, 2014, 94).

The avoided cost method can be defined as the amount of cost to be encountered if the green infrastructure is damaged or a man-made technology substitute for an ecosystem service (Wang et al, 2014, 94). For example, carbon sequestration is an environmental benefit, but it also has an economic value provided to local or regional economies (Demuzere et al, 2014, 108). Torbay covers 63.75 km^2 in England. Roughly 11.8% of the total land is constituted by forests which equals to 818,000 trees. The forest removes 50 tons of pollutants every year and the estimated value of this amount of carbon is €1,584,000 annually (Rogers et al, 2017).

A study conducted in Portland in 2008 found that about 3,716 m^2 green roof can remove roughly 725 kg of particulate matter every year. This removal resulted in saving $3,024 in healthcare costs annually (Environmental Services City of Portland, 2008 cited in American Rivers et al, 2012, 32).

Contingent valuation is another method which values ecosystem services through the surveying techniques (Wang et al, 2014, 95). After the results of surveys and the willingness to pay are evaluated, it is found how much value the environment is given by people. National Association of Realtors found that 50% of the respondents were willing to pay 10% more for houses that are closer to the protected areas or parks (Benedict and McMahon, 2012, 74).

The last one is hedonic pricing, which is related to the increment of real estate values by means of green infrastructure (American Rivers, 2012, 4; Benedict and McMahon, 2012, 74; Firehock and Walker, 2015, 8). Lands and properties which are adjacent or close to natural assets such as lakes, wetlands, parks, or coastlines have a higher value and market prices (Molla, 2015, 94). These landscape features or natural vegetation areas can add extra value to the building units (Wang et al, 2014, 94). Another study showed that the average price of the properties which were close to the greenbelt was 32% higher than those which were 1 km away (Austin, 2014, 88).

2.2.4 Concluding Remarks for Green Infrastructure Benefits

As noted above, green infrastructure is a tool that hosts processes and functions that ensure ecosystem services to the people (Basnou et al, 2015, 3).

The most important role of the green infrastructure is to get maximum benefits from ecosystem services by integrating nature-based solutions into urban planning and development (Ajuntament de Barcelona, 2017, 70). These services were categorized as provisioning such as food, fresh water and fuel; regulating like climate and flood regulation; cultural such as recreation, spiritual and educational; and supporting such as nutrient cycling and soil formation (Millennium Ecosystem Assessment, 2003, 49).

Table 1 Benefits of Green Infrastructure

Environmental	Social	Economic
Carbon Storage and Sequestration	Recreation	Recreation and Tourism Spending
Air Purification	Health and Well-being	New Job Opportunities
Stormwater Management	Education	Energy Saving
Water Purification		
Mitigation of Urban Heat Island Effect		
Climate Regulation		
Conservation of Biodiversity		
Noise Abatement		

In addition to these services, green infrastructure contributes to build natural capital and forms the basis of a sustainable economy (European Environment Agency, 2011, 8). Also, Chan et al (2012 cited in Basnou et al, 2015, 3) stated that benefits that lie somewhere between human well-being and ecosystems can create economic values.

Since the concept of ecosystem services covers a very broad perspective, the terms of service and function need to be addressed more explicitly in order to be used more effectively in green infrastructure planning. Therefore, Haines Young and Potschin proposed a cascade model (Figure 2.15) to identify differences between services and functions and to propound more clear relation that is flowing from ecosystems to humans (Hansen and Pauleit, 2014, 518).

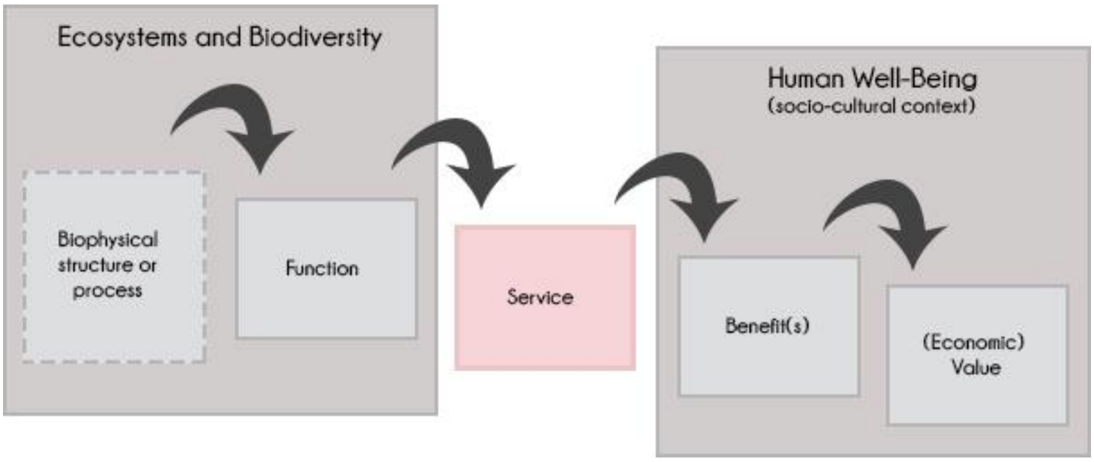

Figure 2.15 Cascade model developed by Hansen and Pauleit

(Hansen & Pauleit, 2014, 519)

Biophysical structures and processes have formed the basis of functions which can be defined as the origin of services for humans. These services result in human well-being and economic value. For example, a wetland is a biophysical structure that provides the absorption of water. In this case, water absorption is a function while flood protection is a service that is. This flow not only contributes to human health but also increases willingness to pay for wetland protection that is an economic value. (Hansen and Pauleit, 2014, 518).

Benedict and McMahon (2012, 3) mention that *"Green infrastructure provides a framework that can be used to guide future growth and future land development and land conservation decisions to accommodate population growth and protect and preserve community assets and natural resources."*

In order to create a holistic green infrastructure approach, different disciplines such as planners, engineers, and landscape architects should work together (Austin, 2014, 6). In this way, ecosystem services will be strengthened and the benefits obtained from nature will be maximized (Ajuntament de Barcelona, 2017).

2.3 Types of Green Infrastructure in Urban Areas

Green infrastructures range from regional to local scale (Bolund and Hunhammar, 1999, 295). Multi-scale nature of green infrastructure can ease the identification of particular biophysical characteristics that are important for benefit production. Therefore, it must be considered in regional and city scale spatial planning (Scholes et al, 2013 cited in Demuzere et al, 2014, 111).

The green infrastructure network includes three fundamental elements which are hubs, links and sites (Figure 2.16). However, Ahern identifies the same approach with different terminology: patches, corridors and the matrix (Firehock and Walker, 2015, 11). Regardless from the terminology, landscapes and ecosystems are connected by green infrastructure network which is composed of hubs, corridors and sites (Benedict and McMahon, 2012, 13).

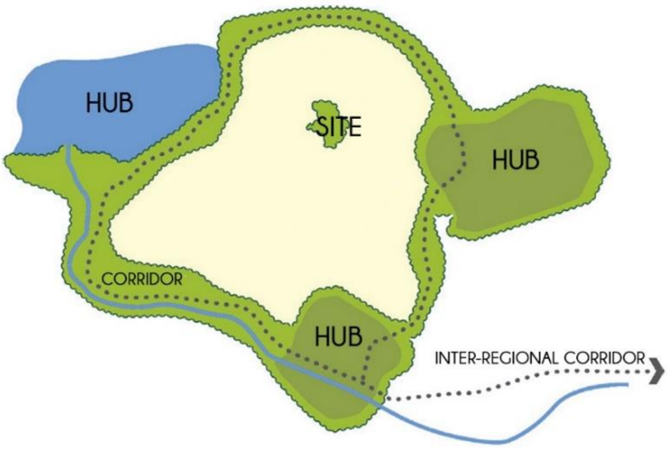

Figure 2.16 Green infrastructure structure which composed of hubs, corridors and sites
(Firehock and Walker, 2015)

2.3.1 Regional Scale

Focusing on different spatial scales may help to connect the capacities and activities of various local actors thereby it can contribute to the holistic approach of green infrastructure regionally (Wyborn and Pixler, 2013 cited in Demuzere et al, 2014, 111). Hence, hubs and corridors are important elements of green infrastructure in regional scale. Jones and Davies (2017, 306) indicate that *"it is especially important when planning for green infrastructure to remember that the whole is greater than the sum of the parts."*

A hub can be defined as generally homogeneous nonlinear area that varies from its surroundings (Ahern, 2007, 271; European Environment Agency, 2011, 65). It accommodates multiple critical functions such as habitat for wildlife and people, sources and nutrients for species, and movement space for ecological processes (Ahern, 2007, 271). Hubs can be formed in different sizes and shapes including natural and recreational areas such as forest, farmland and wetland as well as regional parks and protected areas like state parks and national wildlife refuges (Benedict and McMahon, 2012, 13).

A corridor is considered to be the connection that holds together hubs (Benedict and McMahon, 2012, 13). It helps not only to sustain vital ecological processes by providing the movements of animals, plants, and nutrients but also to support the health of wildlife populations by providing sufficient space for their habitats (Ahern, 2007, 271; Benedict and McMahon, 2012, 13). Moreover, some types of corridors may offer recreational opportunities such as bike and pedestrian paths while the others create a boundary for urban development including greenbelts and greenways (Benedict and McMahon, 2012, 13).

Elements of green infrastructure are more resilient when it is a part of a larger system because they contribute more to the integrity of the system (Weber et al, 2006, 104). It can be practiced on all spatial levels, from protected areas at a regional level, to urban interventions, such as plant cover, the trees lining the streets and sustainable drainage systems (Ajuntament de Barcelona, 2017). Figures below show the examples of green infrastructure at regional scale. Figure 2.17 belongs to Yedigöller National Park in Bolu while Figure 2.18 shows a pasture on which sheep graze in Dorset. Figure 2.19 shows Vondelpark in Amsterdam. The last one, Figure 2.20, shows Kızılırmak Delta Wetland in Samsun.

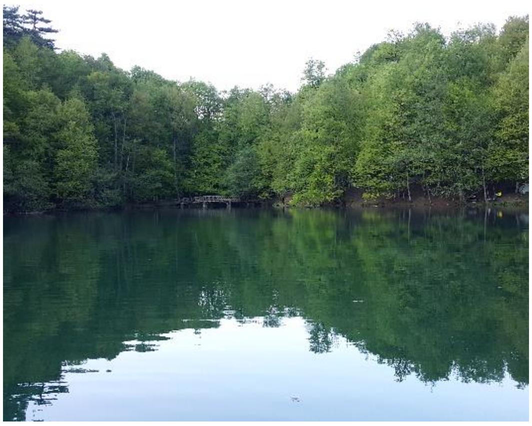

Figure 2.17 Yedigöller National Park in Bolu

(Personal Archive)

Figure 2.18 A pasture in Dorset

(Personal Archive)

Figure 2.19 Vondelpark in Amsterdam

(https://www.cool-cities.com/vondelpark-6223/)
[Accessed: 20.11.2020]

Figure 2.20 Kızılırmak Delta Wetland and Bird Sanctuary

(https://www.milliyet.com.tr/galeri/kizilirmak-deltasi-bir-doga-harikasi-2369286)
[Accessed: 20.11.2020]

2.3.2 City Scale

While hubs and corridors mostly refer to the regional scale, sites are generally associated with city-scale examples of green infrastructure. Unlike hubs, sites are not a part of a larger and interconnected network. Although they are smaller than hubs, they provide ecological, economic, and social benefits that hubs and corridors provide. Protecting the habitats and biodiversity, and ensuring space for recreation and relaxation are among these benefits (Benedict and McMahon, 2012, 14).

If there is not enough space is available to implement hubs and corridors, sites can be preferred. For example, in a densely urban area it can be mostly seen individual trees whereas in the urban periphery forests and woodlands are domestic (Jones and Davies, 2017, 306). In other words, green infrastructure elements in city scale focus on a multifunctional green space network in urban environments while in regional scale deal with the connection between wider landscape components. (European Environment Agency, 2011, 30).

It is believed that implementation of a green infrastructure in redevelopment projects is more challenging in comparison with projects in vacant areas (Jones and Davies, 2017, 2). Green infrastructure types in city scale, such as street trees and green roofs, produce an appreciable effect by absorbing harmful pollutants, providing a cooling effect and reducing eneryg costs of buildings. When local governments notice these numerous benefits of types of green infrastructure in city-scale, they will more include it in redevelopment projects in city center and infill locations (EPA, 2016, 1).

If there are various planning levels such as region, city or local level, planning policies and approaches should be in a hierarchy. For example, if it is aimed to improve the air quality at regional scale, this aim should be maintained at the city-scale. Therefore, spatial decisions in the neighborhood master plan should be determined based on the regional plan (Jones and Davies, 2017, 306). Studying with these terms which are hubs, corridors and sites is helpful to comprehend the sustainable transfer of ecosystems to the future because it constitute the components of landscape (Leitao and Ahern, 2002 cited in Lovell and Taylor, 2013, 1449).

Green roofs, bioswales, rain gardens, street trees, parks, private gardens, and many more examples can be given to the sites mentioned on the city-scale. However, among these, green roofs with multiple benefits become prominant more. Indeed, rooftop areas, which are traditionally considered as an idle space, are vegetated to compensate for the inadequate open green space in the ground (Oberlander et al, 2002, 1). Green roofs reduce the unfavourable impacts of urbanization and offer various ecological, social and economic benefits (Shafique et al, 2018, 757). Many countries have included green roofs in their project and policies for different purposes. For example, Switzerland use green roof as tool for conserving biodiversity (Brenneisen, 2006) when Germany implement it to provide sustainable stormwater management (Liberalesso et al, 2020). Figures below show the examples of green infrastructure at city scale. Figure 2.21 belongs to a green roof in Portland while Figure 2.22 shows a bioswale in Portugal. Figure 2.23 belongs to a playground in İznik while Figure 2.24 shows a line of plane trees in London.

Figure 2.22 Portland's Green Roofs

(https://www.portlandoregon.gov/bes/44422) [Accessed: 09.05.2021]

Figure 2.21 A bioswale in Portugal

(https://walkablewpb.files.wordpress.com/2014/12/sw12thst_photo.jpg) [Accessed: 20.11.2020]

Figure 2.23 A playground in İznik

(Personal Archive)

Figure 2.24 A line of plane trees in a London street

(https://www.nhm.ac.uk/discover/uk-tree-identification.html) [Accessed: 20.11.2020]

The following chapters will elaborate the green roof approach, as part of the green infrastructure at city/neighborhood scale, and examine it with regard to its ecosystem benefits, its role in adapting to climate change, and particularly which tools are introduced in green roof implementations in different spatial scales.

CHAPTER 3

GREEN ROOFS

"Nature is the inspiration for all ornamentation"

Frank Lloyd Wright

Climate change can be defined as a shift in weather patterns. It causes unprecedented events such as rising sea level, extinction of species, and extreme droughts (United Nations, 2020). The anthropogenic development and increase in impervious surfaces in the urban areas are the main reasons for climate change (Herrera-Gomez et al, 2017, 575).

These environmental problems can be solved with green infrastructure approach because it focuses on different principles which are connectivity, multifunctional and multi scale approach. Firstly, connectivity enables not only physical connections but also functional connections among green spaces at different scales (Ahern, 2007, 269). Connectivity among greenspaces provide the continuity of ecological processes and enhance species dispersal (Pauleit et al, 2011, 273). Dixon and Wilkinson (2016, 2010) specified that green roofs have the ability to connect isolated ecosystems by creating green corridors through urban areas. Multifunctionality combines different functions which are environmental, social and economic of a single green space (Pauleit et al, 2011, 274). Shafique et al states that green roofs are designed to support multiple environmental, social and economic benefits. The last principle of green infrastructure is multi scale approach. It refers to applicability on different scales, from building scale to regional scale (Hansen and Pauleit, 2014, 517). It is possible to discuss the benefits of the green roof in the neighborhood and city scale as well as in the building scale (Peng and Jim, 2013, 599). Hence, because of these characteristics of green roof is one of the best tool to deal with the environmental problems and achieve the sustainable future.

Even though a rooftop is traditionally considered unusable and undervalued (Oberlander et al, 2002, 1), it can be one of the most convenient tools to create more resilient cities (Sutton, 2015, 3) because approximately 20-25% of total urban surface area consist of roofs (Besir and Cuce, 2018, 915). Consequently, the green roof ensures the maximum utility for urban areas by providing ecosystem services such as reducing the urban heat island and mitigating stormwater runoff (Weiler and Scholz-Barth, 2009, 1).

Due to the population increase, land use functions are changed while green spaces are decreasing especially in city centers and its surroundings. Natural areas are replaced by functions with impervious surfaces such as buildings, roads and parking lots (Getter and Rowe, 2006, 1276). Increase of these surfaces causes negativities such as urban heat island, increased stormwater runoff, decreased air quality, habitat loss etc. It is possible to reduce these adverse impacts at a certain level by implementing green roofs.

Green roof is one of the effective sustainable measures that can be taken against the negative effects of loss of green spaces in densely built-up areas (Dixon and Wilkinson, 2016, 2; Getter and Rowe, 2006, 1276; Shafique et al, 2018, 757). It has been increasingly recognized in time due to the decrease of available spaces in the cities for green areas. Green roofs not only contribute to healthy and good-quality environments in cities, but also compensate for the lost value of nature by the intervention which is defined as any changes affecting the balance of nature (Ngan, 2004, 24). Although at present they are mostly implemented with ecological drivers, it is known that the first examples of green roofs date back to the period between circa 4000 BC until 600 BC (Osmundson, 1999 cited in Jim, 2017, 70).

3.1 History of Roof Gardens

The earliest known examples of green roof in the ancient history dates back to 4000 BC are Ziggurats in Mesopotamia which were constructed as temples (Weiler and

Scholz-Barth, 2009, 1). These structures were constructed as terraces elevated from the ground with simple vegetation by ancient Mesopotamian civilizations such as Assyrian, Babylonians and Sumerians (Leick, 1988, 1-18). The vegetation on terraces was designed for ornamental purposes and shading. Stairs and ramps among terraces which were designed as a part of exterior living spaces provided accessibility for public (Jim, 2017, 70).

The Hanging Gardens of Babylon (Figure 3.1), one of the ancient seven wonders of the world, are the most famous symbol of green roofs. The deep soil layer allowed shrubs and trees to grow. Moreover, a special irrigation system was constructed to irrigate the luxurious plants, which took the water from River Euphrates (Abass et al, 2020, 3). It is not only the ancient origin of the roof greening idea for hedonic purposes, but also the pioneer of installing an elevated vegetating to an artificial structure with an advanced technology in its era (Jim, 2017, 70).

In addition to them, archaeological excavations have shown that Romans also used the concept of green roof in their domestic structures (Abass et al, 2020, 3). The open green spaces have been designed as an extension of the living unit.

Figure 3.2 Hanging Gardens of Babylon

https://steamcommunity.com/sharedfiles/filedetails/?id=1138831298 [Accessed: 10.07.2020]

Figure 3.1 Villa of Mysteries in Pompeii

https://news.yahoo.com/pompeii-villa-mysteries-opens-fresh-start-italy-heritage-222643563.html [Accessed: 10.07.2020]

The best example of the Romans' green roof, is Villa of Mysteries in Pompei, comprised a U-shaped terrace arcade which has soil and vegetation layers on its top (Jim, 2017, 70). Figure 3.2 shows Villa of Mysteries in Pompei.

Atlantic countries have covered their roofs with sod to prevent the cold weather (Eren, 2018, 2; Osmundson, 1999 cited in Peterson, 2001, 36). For example, the traditional house of Vikings (Figure 3.3), named as longhouse, is one of the oldest examples of green roofs which was built to be protected from harsh climatic conditions such as heavy rains and storms (Jim, 2017, 71). Hereby, green roofs have begun to be built not only for ornamentation but also protection from environmental impacts (Abass et al, 2020, 5). Figure 3.4 shows that thatched roof in Ethiopia which was built for extreme heat waves.

Figure 3.3 Traditional longhouse of Vikings in Iceland

(https://www.turfonline.co.uk/blog/green-roofing-for-winter-insulation/) [Accessed: 10.07.2020]

Figure 3.4 Thatched roof in Ethiopia

(https://www.robertharding.com/preview/1270-20/traditional-mud-hut-thatched-roof-rural-ethiopia-africa/) [Accessed: 10.07.2020]

After this period, modernist approaches regarding the green roof were began to accrue with the Renaissance impressions. Seven oak trees were planted in the small rooftop of the Tower of Guinigi in Italy (Figure 3.5). Meawhile, Palazzo Piccolomini in Italy (Figure 3.6) was built along the slope of a ridge so the street-level space of Palazzo became both a courtyard and a rooftop (Peterson, 2001, 29).

In virtue of the increasing technological developments and the widespread use of flat roof, green roof technology gained momentum in the mid-1800s. In 1867, a German master builder Carl Rabitz provided new insight with regard to the flat roofs created an extra space for amenity. He created the functional space in his own villa roof whose model was exhibited in Paris Exhibition (Constantinidis et al, 2009, 318).

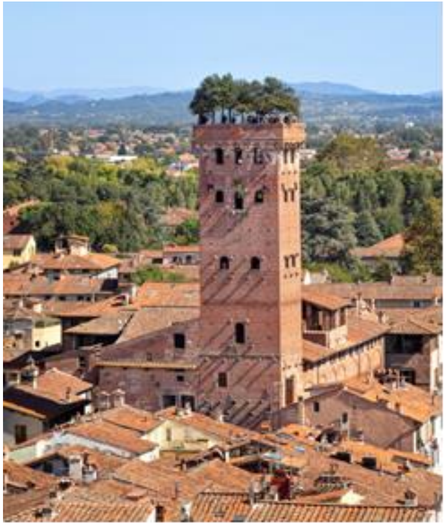

Figure 3.5 Guinigi Tower in Italy
(https://lovefromtuscany.com/where-to-go/cities-in-tuscany/lucca/guinigi-tower/)
[Accessed: 10.07.2020]

Figure 3.6 Palazzo Piccolomini in Italy
(http://www.iccd.beniculturali.it/it/641/campagne-fotografiche/3854/pienza-il-centro-storico)
[Accessed: 10.07.2020]

In the beginning of 20th century, roof gardens gained importance whereby Le Corbusier, Alvar Aalto and Frank Lloyd Wright brought about a different point of view to architecture (Abass et al, 2020, 2). Le Corbusier connoted that roof gardens are one of the five basic elements of modern architecture. He emphasized the importance of the fact that unused flat roofs should be integrated into the daily life of the residents. Thus, rooftops could be part of the social recreation system of the city (Peterson, 2001, 42). According to him, ideal city plan included the consolidation of open space both on the rooftops and on the ground (Constantinidis et al, 2009, 318). Figure 3.7 shows the green roof on Le Corbusier’s La Tourette.

Alvar Aalto's designs enable people to observe the movement of nature from exterior to interior space. Therefore, he designed his houses inspiring from the natural texture around them (Ayalp, 2011, 29). As a result, the green roofs were implemented in his designs to merge the nature with the houses (Abass et al, 2020, 2). Figure 3.8 shows the green roof on Villa Mairea designed by Alvar Aalto.

Figure 3.7 Le Corbusier's La Tourette
(https://monopinion939.wordpress.com/2018/10/24/le-corbusier-1887-1965-une-maison-est-une-machine-a-habiter/) [Accessed: 10.07.2020]

Figure 3.8 Alvar Aalto's Villa Mairea
(http://ideasgn.com/architecture/villa-mairea-alvar-aalto/) [Accessed: 10.07.2020]

Likewise, Frank Lloyd Wright introduce the green roof as an extension of indoor spaces. He has used organic colors and simple geometric shapes to integrate the buildings into the natural environment. The Wingspread (Figure 3.9) in Wisconsin and the Imperial Hotel in Tokyo are the examples of Wright's designs to adopt rooftop terraces as the garden spaces (Peterson, 2001, 42).

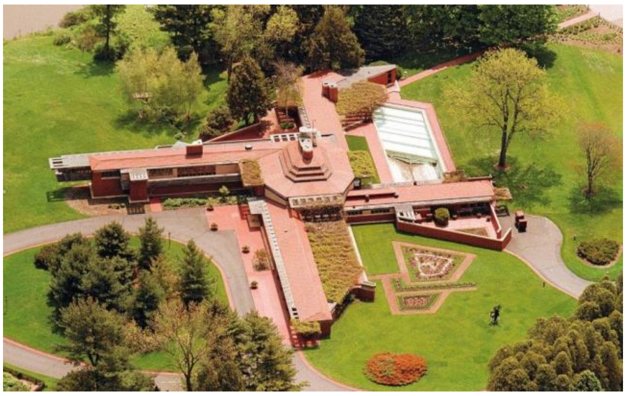

Figure 3.9 Frank Lloyd Wright’s Wingspread
(https://franklloydwright.org/site/wingspread/) [Accessed: 27.12.2020]

In the pre-war era, one of the most inspirational rooftop garden is Rockefeller Center (Figure 3.10) which is first of United States, includes five separate gardens on it. It was built between 1933 and 1936 whose purpose is providing visual amenity such as beautiful green space for the surrounding skyscrapers. The design includes luxuriant landscape elements such as flower beds, fountains, bird sanctuary, sculptures and vegetable gardens ("Rockefeller Roof Gardens", 2018). In spite of dead of some of the plants, it still subsists as an extensive green roof and inaccessible to the public.

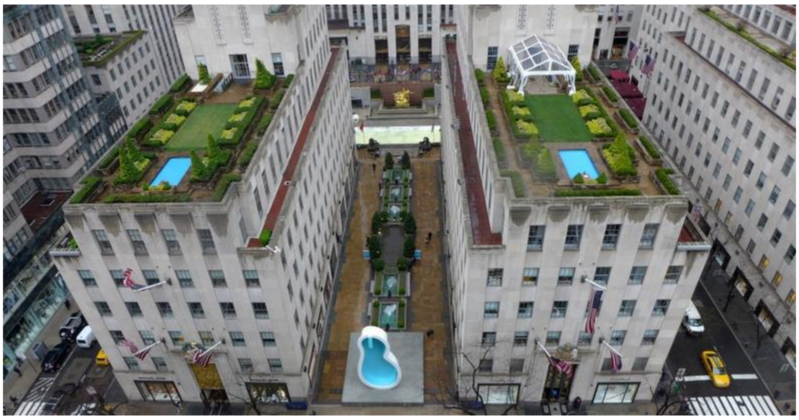

Figure 3.10 Green roof on Rockefeller Center
(https://untappedcities.com/2014/05/01/daily-what-the-hidden-rooftop-gardens-of-rockefeller-center/)
[Accessed: 10.07.2020]

Another important example is the roof of Derry and Toms Department (Figure 3.11 and Figure 3.12) store in London. It was a quite big roof garden which was covering 6,000 m^2. Like Rockefeller Center, it has several gardens and numerous distinctive functions; such as stone arches, flower beds, canals, towers, climber green walls and waterfalls. Also, in 1986 the gardens were awarded Grade II listing by English Heritage. Although, some components were destroyed in World War II, after the restoration the roof garden completed, visits continued there until it closed in 2018 ("Derry and Toms", 2007).

Figure 3.11 Top View of roof garden on Derry and Toms Department Store

(https://www.standard.co.uk/go/london/attractions/kensington-roof-gardens-reopen-2020-a3948276.html) [Accessed: 10.07.2020]

Figure 3.12 Roof garden on Derry and Toms Store

(https://www.greenroofs.com/projects/kensington-roof-gardens-the-roof-gardens-derry-toms/) [Accessed: 10.07.2020]

Even though the first examples of the green roof were constructed for ornamentation, aesthetic and recreational purposes, their environmental contributions have been recognized started to arise since the 1980s (Ngan, 2004, 1). Gradually, policies, incentives and subsidies have been developed in different countries to encourage people to install the green roof (Ngan, 2004, 1; Aras, 2019, 494).

Although green roofs were implemented on a lot of buildings around the world at the beginning of the 20th century, its first efficient use in modern buildings started in Germany through the technological advances (Eren, 2018, 3). Germany's green roof technology began to develop in the 1960s. In order to reduce fire risk of highly flammable tar located on the roof, the method of covering tar with sand and gravel was developed. After the method was implemented, seeds on the roof material naturally turn into the meadow. The roofs which are built by this method have been durable and totally waterproof since 1980 (Getter and Rowe, 2006, 1277).

In the 1970s, green roofs were considered as a building design approach. In the 1980s, interest in green roof technology increased and studies related to the ecological benefits of green roof were accelerated. As a result, the term of the extensive green roof was introduced (Ngan, 2004, 1).

3.2 Classification of Green Roof

3.2.1 Intensive Green Roof

Notwithstanding the vegetated roof is usually called as green roof, eco-roof, living roof and roof garden are also terms frequently used. Basically, the term roof garden has a different meaning than others (Shafique et al, 2018, 757). It is also named as an intensive green roof that refers to the open green space on the rooftop with different kinds of vegetation which include recreational activities and visual amenities for the inhabitants. In other words, a roof garden is a place that is designed for recreation, amenity, and aesthetic purposes (Oberndorfer et al, 2007, 825). In order to achieve these goals, the landscape elements are more important in the design of intensive green roofs. For example, pathways, ponds and gardens can be used in the design process of the intensive green roofs like parks (Weiler and Scholz-Barth, 2009).

It generally has a thick soil layer, usually more than 15 cm, in order to allow to grow rooted plants such as shrubs and trees (GRHC, 2006 cited in Sutton, 2015, 6-8). Because of these characteristics, intensive green roofs require irrigation, fertilization, high capital cost and high maintenance (Vijayaraghavan, 2016, 741). The plant species on the intensive green roof is richer than the extensive green roof (Figure 3.13) by means of these characteristics Also, both construction and maintenance processes of intensive green roofs are more complex than extensive ones in terms of design, size, cost and, structural strength (Weiler and Scholz-Barth, 2009). For this reason, they are mainly implemented in flat roofs of new buildings due to the high structural weight and its necessities (Getter and Rowe, 2006). Figure 3.14 shows intensive green roof on Acros Fukuoka Prefectural International Hall in Japan.

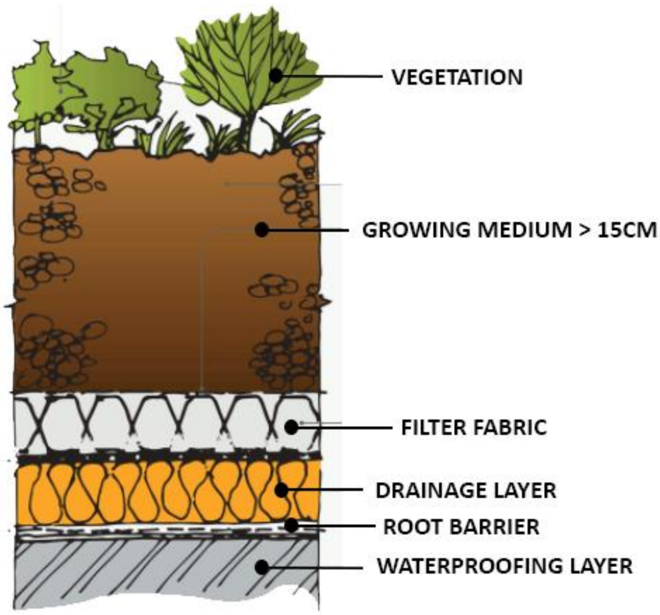

Figure 3.13 Layers of intensive green roof
(http://www.buildmagazine.org.nz/articles/show/the-gen-on-green-roofs
[Accessed: 10.07.2021]

Figure 3.14 Intensive green roof on Acros Fukuoka Prefectural International Hall in Japan
(https://www.greenroofs.com/projects/acros-fukuoka-prefectural-international-hall/)
[Accessed: 12.05.2021]

3.2.2 Semi-intensive Green Roof

Green roofs with soil thickness from 10 cm to 20 cm depth refer to the semi-intensive green roofs (Figure 3.15) which can represent the qualifications of both extensive and intensive green roofs (GRHC, 2006 cited in Sutton, 2015, 6-8). It can be defined as the combination of the ecological benefits of extensive green roof and aesthetic benefits of an intensive green roof (Dunnett and Nolan, 2004, 305). Semi-intensive green roofs accommodate a wider range of vegetation types like small shrubs and woody plants because of the moderately thick soil layer. Irrigation and maintenance activities may vary depending on the type of plants used (The Green Roof Organisation, 2014). A semi-intensive green roof can be designed if the building to be designed by aesthetic concerns is not capable of carrying the weight of the intensive green roof (Dunnett and Nolan, 2004, 305). Figure 3.16 shows semi-intensive green roof on California Academy of Sciences.

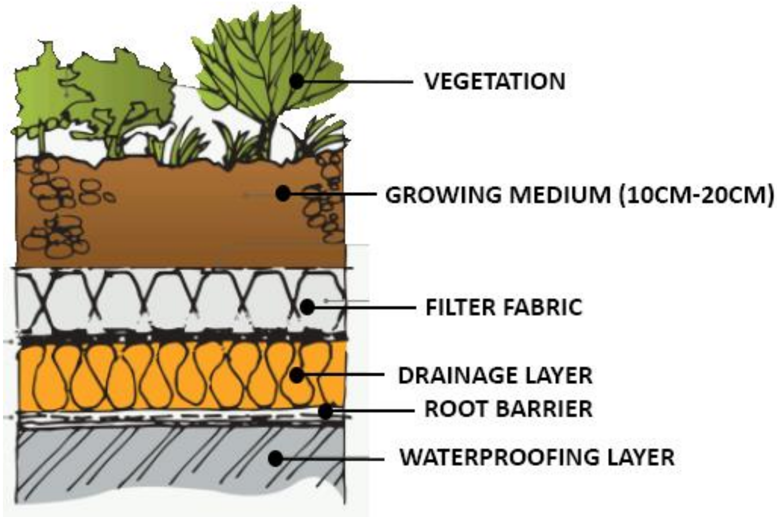

Figure 3.15 Layers of semi-intensive green roof

(http://www.buildmagazine.org.nz/articles/show/the-gen-on-green-roofs
[Accessed: 10.07.2021]

Figure 3.16 Semi-intensive green roof on California Academy of Sciences

(https://www.greenroofs.com/projects/california-academy-of-sciences-cas-living-roof/)
[Accessed: 10.07.2021]

3.2.3 Extensive Green Roof

The most common of these three types are extensive green roofs because of the limited building restrictions, low cost and low maintenance needs (Vijayaraghavan, 2016, 741). The extensive green roofs that have a thinner soil layer, generally less than 15 cm, in comparison with the intensive ones (GRHC, 2006 cited in Sutton, 2015, 6-8). Due to the shallower soil layer, extensive green roofs accommodate limited types of plant species such as grasses, mosses, and succulents (The Green Roof Organisation, 2014). Besides, these plants must require minimal maintenance and survive harsh environmental conditions like drought and extreme heat (Oberndorfer et al, 2007, 825). As a result, sedums which are the type of succulents, meet all these criteria are generally used on extensive green roofs. Sedum species also cover almost the entire roof through the ability of easy propagation (Getter and Rowe, 2006, 1281; Weiler and Scholz-Barth, 2009, 12; Vijayaraghavan, 2016, 744).

Extensive green roofs also require low capital cost and minimal maintenance because they do not need irrigation and fertilization process (Ngan, 2004, 2; Vijayaraghavan, 2016, 741). They can be implemented not only on the roof of new buildings but also on existing buildings because they have lower structural weight. The roof does not necessarily need to be flat for the installation of the extensive green roof, it can be implemented on the roofs up to 40 percent slope (Environmental Services City of Portland, 2009, 12). It does not have to open to people, because the fundamental purpose of the extensive green roof is to reduce negative environmental impacts of urbanization such as stormwater attenuation, mitigation of urban heat island, improvement of air quality (Getter and Rowe, 2006, 1276). Figure 3.18 shows the extensive green roof on Copenhagen cruise ship terminal.

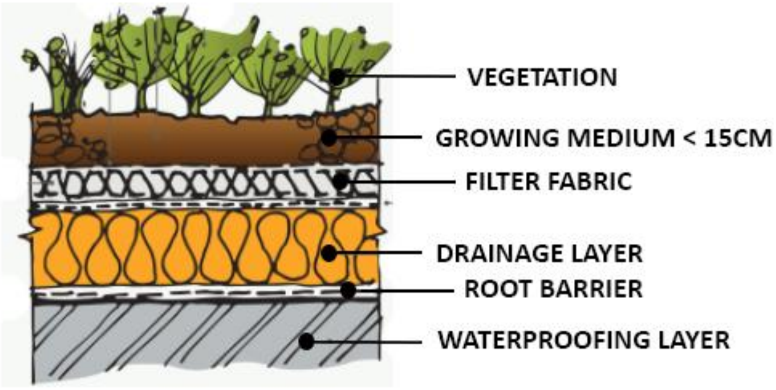

Figure 3.17 Layers of extensive green roof

(http://www.buildmagazine.org.nz/articles/show/the-gen-on-green-roofs
[Accessed: 10.07.2021]

Figure 3.18 Extensive green roof on Copenhagen cruise ship terminal

(https://inhabitat.com/a-massive-green-roof-sits-atop-a-copenhagen-cruise-ship-terminal/)
[Accessed: 10.07.2021]

Table 2 Classification of green roof

	INTENSIVE	SEMI-INTENSIVE	EXTENSIVE
			
Substrate Depth	More than 15 cm	Between 10 cm - 20 cm	Less than 15 cm
Plant Types	Shrubs and Trees	Grasses, Herbs, Small Shrubs	Grasses, Mosses, Succulents
Maintenance	High	Moderate	Low
Irrigation	Regularly	Periodically	No Need
Purpose of use	Mostly Aesthetic and Recreation	Environmental, Aesthetic	Environmental Concerns
Cost	High	Moderate	Low

3.3 Design Principles and Construction Elements

3.3.1 Layers

Green roof includes various components such as vegetation, growing medium or substrate, filter fabric, drainage mat, protection layer, root barrier, water proofing membrane. Furthermore, it needs additional components such as irrigation depending on the type of the green roof and climate conditions (Besir and Cuce, 2018, 917; Berardi et al, 2014). Figure 3.19 shows the layers of green roof.

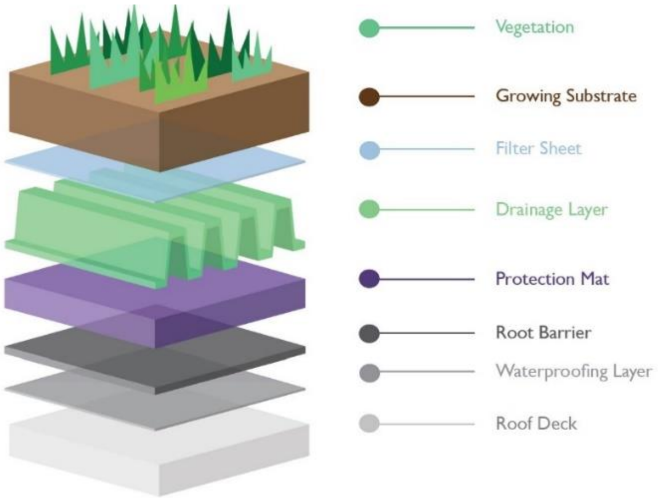

Figure 3.19 Layers of green roof
(State of Victoria, 2014, 67)

3.3.1.1 Vegetation

The most important criterion in plant selection to be used in green roof design is whether the roof will be intensive or extensive. This is directly related to the depth of the soil layer because, plant diversity, irrigation, and maintenance increase as soil depth increase (Perez and Coma, 2018, 68). Extensive green roofs are limited to herbaceous, mosses, and succulents like sedums that are resistant to harsh environmental conditions usually grow in a shallow substrate (Getter and Rowe, 2006, 1277).

Extensive green roofs are designed to take advantage of ecological benefits rather than aesthetic concerns (Perez and Coma, 2018, 66). Hence, the most important characteristics of plants that are used in extensive green roofs are requiring low maintenance and little or no irrigation (Environmental Services City of Portland, 2009, 17). Due to the requirement of low maintenance, plants should be both self-sowed and self-sufficient (Wong et al, 2007 cited in Perez and Coma, 2018, 66).

Moreover, Vijayaraghavan (2016, 744) states that vegetation for extensive green roofs should tolerate drought conditions, survive with minimal nutrient conditions and have soft and short roots.

Oberlander et al (2002, 6) stated in the introductory manual about green roofs for the Canadian Government that if the plants used on the green roof are adapted to the local climate, they will be more resistant to climatic factors such as rainfall, wind and temperature. Thus, local plants on the green roof help to reduce the cost of irrigation and maintenance (Bevilacqua et al, 2016 cited in Besir and Cuce, 2018, 917). In addition to the locality of plants, increasing the diversity of plants used on extensive green roof maximize the effectivity of the roof (Berardi et al, 2014, 415).

Another significant factor in choosing plant for extensive green roof is the purpose of the roof implementation such as stormwater management or enhancement of biodiversity. After the purpose has been determined, plants should be selected for this purpose. For example, if the purpose is stormwater management, leaf size, transpiration characteristics and the ability to retain water must be considered (The Green Roof Organisation, 2014, 17). Similarly, Berardi et al (2014, 414) state that characteristics of plants such as albedo, leaf era index and stomatal resistance affect the heat exchange of a green roof. Figure 3.20 shows some sedum types that are used in green roofs.

Figure 3.20 Examples of sedum types. From left to right, ivory towers, pink jelly bean, red pagoda, coral bells

(https://succulentsbox.com/products/types-of-succulents-printable-succulents-art) [Accessed: 14.12.2020]

3.3.1.2 Growing Medium (Substrate)

The growing medium not only provides physical support for plants but also holds water and nutrients for vegetation growth (Perez and Coma, 2018, 71). Multiple factors must be considered to create the desired growing medium. They are high water holding capacity, lightweight, high rate porosity, good plant anchor, minimal organic content and resistance to water and wind erosion (Vijayaraghavan, 2016). To provide these desired considerations, it must contain a defined ratio of organic and inorganic materials (Sutton, 2015, p. 8).

The organic fraction both keeps water and microbial populations, and provide nutrients such as peat and mulch (Sutton, 2015, p. 8). Even though organic matter encourages plant growth and improves the water content of growing medium, it not only degrades and subside over time but also prevents the water flow. Therefore, unless it used in specified ratios, it shortens the life of green roof (Perez and Coma, 2018, 71). FLL, which is the German basic standards for green roofs, recommends that extensive green roofs include 4-8% organic matter (FLL, 2002 cited in Vijayaraghavan, 2016, 746). The inorganic fraction provides a structure that resists freeze-thaw cycles and accelerates permeability. Pumice, ash, zeolite, sand, vermiculite and even recycled materials like porcelain and crushed bricks are the most common inorganic constituents (Perez and Coma, 2018, 71).

Since commercial growing mediums are constituted considering the climate conditions, they might not show the desired performance in a different geographical location. Figure 3.21 shows some materials that are used in growing medium.

Figure 3.21 Examples of components in a growing medium. From left to right, sand, compost, pumice-stone and crushed brick

(https://greenroof.se/wp-content/uploads/2017/04/Swedish-handbook.-Translated-short-version.pdf) [Accessed: 14.12.2020]

For this reason, as in the plant selection, it is recommended that local materials should be used while composing the growing medium to install the green roof cheaper and efficiently (Vijayaraghavan, 2016, 745). Deeper growing media provides greater vegetation support and moisture retention. However, thickness of growing medium for extensive green roof should be between 5 and 15 cm relying on the load capacity of the building (Environmental Services City of Portland, 2009, 16).

3.3.1.3 Filter Fabric

The filter layer is located between the growing medium and the drainage layer that prevents small particles of growing medium such as soil fines and sediments from mingling and clogging the drainage layer (Vijayaraghavan, 2016, 747). It can be woven or non-woven geotextile fabrics whilst the main material is polypropylene or polyester (Perez and Coma, 2018, 71). There are multiple types of filter fabrics in the market. However, when selecting the most appropriate filter fabric, it is important to consider characteristics of the fabric that affect the flow rate and permeability such as tensile strength, pore space, weight, and resistance to rot (Weiler and Scholz-Barth, 2009, 165).

The water absorption capacity of the green roof is improved through the ability of water holding of filter fabric. Wong and Jim (2014 cited in Vijayaraghavan, 2016, 747) state that "a non-woven geotextile filter fabric absorbed approximately 1.5L of water/m^2."

3.3.1.4 Drainage Layer

The purpose of this layer is to keep the balance between water and air in the green roof system at an optimal level (Perez and Coma, 2018, 72). The drainage layer plays a key role in removing excess water from the roof since the plant roots need a ventilated and non-water-logged growing medium. Also, it stores water for later use by plants when necessary (Getter and Rowe, 2006, 1277). Furthermore, it provides protection for waterproof membrane and helps to ensure energy efficiency in buildings (Perez et al, 2012 cited in Shafique et al, 2018, 763). Mostly, two major types of drainage layers are used.

Drainage modular panels (Figure 3.22): It is made of polyethylene or polystyrene with compartments so that it can hold the water for later use or evacuate excess water (Vijayaraghavan, 2016, 747).

Granular porous materials (Figure 3.23): It consists of porous soil that have large pore spaces in order to hold the water such as expanded shale, expanded clay, crushed brick and stone chips (Shafique et al, 2018, 763).

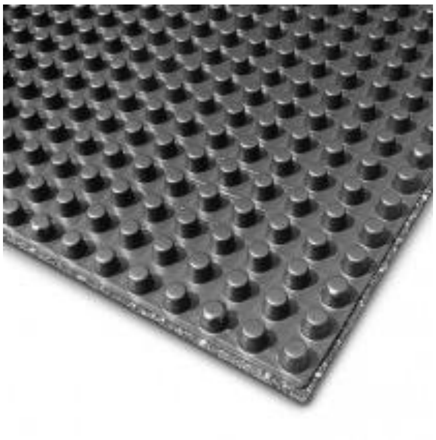

Figure 3.22 Drainage modular panel

https://www.zinco.ca/reference-library/component-detail/drainage-elements [Accessed: 14.12.2020]

Figure 3.23 Granular porous materials

(Coma et al, 2016, 1109)

The selection of these drainage types depends on scale of green roof, construction requisites, vegetation type and cost. Generally, small-scale installations such as residential buildings use the granular materials for the drainage system of a green roof. However, it is not suitable for the steeper roofs. It can only be implemented in slightly angled (less than 5°) or flat roofs (Vijayaraghavan, 2016, 747). Moreover, these soils may require summer irrigation if stormwater management may not reach an optimum level (Environmental Services City of Portland, 2009, 15).

On the other hand, Vijayaraghavan (2016, 747) remarks that "drainage modules are well suited for large-scale installations and can suit flat as well as moderately sloped surfaces". The main constraints of drainage modules, which are easier to install compared to porous materials, are cost and disposal (Shafique et al, 2018, 763).

3.3.1.5 Root Barrier and Waterproofing Layer

The root barrier (Figure 3.24) layer provides protection for building against root penetration (Perez and Coma, 2018, 72). It is mandatory in the intensive green roof because it includes more rooted plants such as shrubs and trees, while it is optional for an extensive green roof (Shafique et al, 2018, 763). Perez and Coma (2018, 72) indicate that "it can be embedded in the waterproofing membrane, or maybe a separate membrane placed above the waterproofing membrane". Hence this material may be chemical as well as physical. There are several commercial root barriers in the market such as metal and hard plastic sheets (Vijayaraghavan, 2016, 747). The latter can be composed of bitumen, polyvinyl chloride (PVC), synthetic rubber, or polyethylene (Shafique et al, 2018, 763).

The waterproofing membrane (Figure 3.25) is essential for the green roof in order to prevent the leakages of water because in comparison to traditional roofs, the green roof has more chances to leak because of the high water content and moisture (Shafique et al, 2018, 763). Although the main role of the waterproofing layer is to protect the building from any action of water (Perez and Coma, 2018, 72), it also protects from chemical and physical damage (Shafique et al, 2018, 763) There are many alternatives like modified-bitumen sheets, liquid-applied membranes and thermoplastic membranes (Townshend, 2007 cited in Vijayaraghavan, 2016, 747). The selection of the most appropriate membrane depends on the type and life expectancy of the green roof and cost (Vijayaraghavan, 2016, 747). If these factors take into consideration, more durable green roofs are installed (Shafique et al, 2018, 763).

Figure 3.24 Root barrier

(https://www.fabricgateway.com/topic/root+barrier#&gid=1&pid=33) [Accessed: 14.12.2020]

Figure 3.25 Waterproof membrane

(Tolderlund, 2010) [Accessed: 14.12.2020]

3.3.2 Installation and Maintenance

Before the green roof is implemented, expectations about the green roof, the characteristics of the building and environmental conditions must be analyzed in detail. First, the answer to the question of "why the green roof will be implemented" should be sought. The answer can be social desires such as aesthetics as well as environmental concerns like stormwater management (Environmental Services City of Portland, 2009).

If the roof is chosen to be intensive, accessibility and safety factors need to be provided in the design of green roof (Tolderlund, 2010, 14). On the other hand, plants on the extensive green roof can tolerate foot traffic several times a year, but gravel paths can also be made preferably (Environmental Services City of Portland, 2009).

Structural load capacity of the building and the slope of the roof should be taken into consideration. Depending on the load capacity of the building and slope of the roof, the layers may vary and additional materials may be used (Cantor, 2008, 58). After the waterproof membrane is installed, the leak detection test must be performed to make sure that the membrane does not have any leak (Tolderlund, 2010, 29). In addition to these, climatic conditions, amount of rainfall, sunshine duration and wind are important factors in determining the plant selections to be installed on the green roof. Plants can be installed on growing medium with several methods which are seeds, cuttings, plugs and vegetative mats in extensive green roof (Getter & Rowe, 2006, 1281). Figure 3.26 shows some installation methods.

Figure 3.26 Installation methods of plants. From left to right, sedum mat, cuttings, plugs
(https://www.rotsplantenshop.nl/product/sedumtray-place-n-go-1m2/) [Accessed: 14.12.2020]

Afterwards the installation of green roof is completed, a maintenance plan should be made. The vegetation on the green roof needs care and attention like irrigation, fertilizing, weeding, mowing and replanting. Also, both membrane and various roof structures should be controlled regularly. Maintenance periods can be scheduled after natural events such as storms and floods or during the seasonal events including season of invasive species and germination periods (Tolderlund, 2010, 31).

Extensive green roof does not require frequent maintenance and irrigation. It can only require irrigation during the growth period of plants, that is, in the first one or two years of installation, depending on which method the plants are implemented (Cantor, 2008, 58).

Maintenance in extensive green roofs is rare and may generally take place a couple times in a year. This maintenance includes weeding, removing of the drainage system from debris, controlling and maintaining the irrigation system and cleaning the dead plants. The most important task is to do eradicate the invasive weeds that have been accrued on the green roof. However, intensive green roofs require increased level of maintenance compared to the extensive and semi-intensive types. The maintenance procedures in intensive green roofs are same as a park or private garden such as fertilizing, mowing, pruning, and prevention of disease, insect and weed. Yet, the personnel should be trained to the characteristics of green roof. It is prevented that they do not harm the integrity of filter and drainage layers. Yet, the personnel should be trained to the characteristics of green roof in order not to harm the integrity of filter and drainage layers (Nektarios, 2018, 83).

3.4 Benefits of Green Roof in Urban Areas

While all the three types of green roofs offer more or less the same benefits; depending on the type of green roof, depth of soil and plant species on it, the effects of the benefits can differ from each other (Weiler and Scholz-Barth, 2009, 13). However, extensive green roofs are more preferred than the other types because of the purpose, cost and maintenance needs (Oberndorfer et al, 2007, 824).

Although green roofs cannot replace the urban forest, street trees or meadows in the urban areas, they can be used as a tool against the negative effects of climate change by utilizing the impermeable and unused roof surfaces in the city (Oberndorfer et al, 2007, 823; Weiler and Scholz-Barth, 2009, 15).

Green roofs play a significant role to ameliorate the urban ecology by providing the ecosystem services; namely provisioning, regulating, cultural and support services (Sutton, 2015, 5). Provisioning services are the products obtained from the ecosystems while regulating services are benefits obtained from ecosystem processes. Cultural services are non-material benefits obtained from ecosystems. Lastly, supporting services are ecological functions at the basis of production of ecosystem services (The Nature Conservation Centre, 2020, p. 19). Following chapters are categorized benefits of green roof as a part of ecosystem services.

3.4.1 Ecological Benefits

As urbanization increases, the conservation of balance between the human requirements and ecological concerns is quite critical not to deteriorate the ecological systems (Bianchini and Hewage, 2012, 161). Stormwater management, mitigation of urban heat island, enhancement of biodiversity, mitigation of air and noise pollution represent the ecological benefits of green roof. (Getter and Rowe, 2006, 1278-1280; Oberndorfer et al, 2007, 823; Vijayaraghavan, 2016, 741). These ecological benefits also contribute to the regulating services.

3.4.1.1 Stormwater Management

Flood can be defined as a disaster caused by the rainfall that has not yet reached the drainage systems after heavy rainfall events. Extreme weather conditions and reduction of permeable surfaces are the main reasons of it (Lamond et al, 2016, 86).

Green roof is one of the best means to manage stormwater in urban areas because both the substrate and the vegetation layer are capable of capturing a large amount of water. Turning impermeable structures into porous surfaces not only attenuate the stormwater, but also delay the peak flow (Shafique et al, 2018, 764). When a portion of precipitation is captured by vegetation, it is eventually released back into the atmosphere via evapotranspiration. Likewise, some amount of water which is absorbed in the substrate layer is released by evaporation. The evaporation and transpiration events show that green roofs have a high potential to manage stormwater. (Vijayaraghavan, 2016, 742).

Portland City shows great efforts to solve the problems related to stormwater management. At the end of these efforts, the city succeeded in managing stormwater, extending the duration of peak flows and enhancing the quality of water. While the quantity of stormwater of the traditional roof is 3320 m^3, it is only 1537 m^3 of the green roof (City of Portland Bureau of Environmental Services, 2008, 5).

The ability of stormwater retention depends on not only the characteristics of green roofs such as substrate depth and moisture, plant species, and roof slopes but also environmental conditions like the magnitude and the frequency of rainfall events (Schultz et al, 2018, p.111; Weiler and Scholz-Barth, 2009, 24).

Green roofs with deeper substrate have higher water retention capacity. Feitosa and Wilkingson (2016, 173) studied green roofs with different substrate depth, and observed that the water retention capacity in the shallowest 5 cm green roof was 26%, while the retention capacity rose up to 65% as the substrate thickness increased. However, the stormwater retention efficiencies reduced with the amount of total rainfall. Another study indicates that increasing the depth of the green roof by 50 mm results in a 10% increase in annual absorption (Schultz et al, 2018, 117). In addition to substrate depth, previous substrate moisture content affects the retention capacity of the green roofs. Stormwater retention capacity reduced with the soil moisture content because wet soils absorb less water compared with dry ones (Feitosa and Wilkinson, 2016, 175).

In addition to the substrate characteristics, plant species can affect the reduction amount of stormwater. Nagase and Dunnet (2012 cited in Vijayaraghavan, 2016, 742) studied different plant species that are grass, forb, and sedum and compared their hydrophilic characteristics. It was found that among three of them, grasses are the most effective species to retain stormwater. Grasses are followed by forbs and sedums, respectively.

Furthermore, the roof slope is not an efficient factor alone to increase stormwater retention. However, when it is supported by media composition and depth, it is possible to increase the stormwater retention capacity of the green roof (VanWoert, 2005 cited in Vijayaraghavan, 2016, 742).

Moreover, green roof provides cities with delayed stormwater runoff because water enters the green roof system with vegetation, substrate, filter and drainage layer respectively. After the soil can reach the saturation level, overflow can drain that is why peak flow delayed. Therefore, this delay of the green roof can not only prevent stormwater sewer system overflowing but also reduce the risk of flooding (Sutton, 2015, 86). Compared with the traditional roof, green roof can delay overflow almost 95 minutes (Liu, 2003 cited in Getter and Rowe, 2006, 1278).

3.4.1.2 Mitigation of Urban Heat Island

Urban heat island which originates from the changes of energy balance in urban areas, can be defined as urban areas having several degrees higher air temperatures than countryside (Gill et al, 2007; Susca et al, 2011). Urban heat island can cause many unfavorable conditions from illness and discomfort to heat-related death. In addition to morbidity and mortality, it exacerbates air pollution and increases the consumption of electricity and water (Osmond and Irger, 2016, 39).

The implementation of green roofs on an urban scale can significantly contribute to the reduction of the urban heat island because almost 20–25% of the urban surface comprises the roofs (Susca et al, 2011, 2119). A research related to the technologies which combat urban heat island expresses that the wide-scale application of green roofs can decrease the ambient temperature from 0.3^{o}C to 3^{o}C (Santamouris, 2014, 682).

Impermeable concrete surfaces absorb the incoming solar energy during the day time and reradiate the energy as heat to the atmosphere in the night time. On the contrary, most of the solar energy absorbed by plants is released back into the atmosphere through activities such as evapotranspiration and photosynthesis, directly or indirectly. Therefore, green roofs reduce the urban heat islands by turning water and solar energy into the water vapor (Bass et al, 2002; Aras, 2019). According to a case study conducted in Greece, plants in the green roofs absorb 60% of solar radiation, reflect 27% of it and transmit the last 13% to the soil (Vijayaraghavan, 2016, 742).

Figure 3.27 shows temperature differences between conventional and green roof in Chicago City Hall.

Figure 3.27 Temperature differences between conventional and green roof in Chicago City Hall
(https://www.slideshare.net/pd81xz/xwb2) [Accessed: 14.12.2020]

Plant species, leaf area index, reflectability of the substrate are some of the important factors of green roof in order to regulate the surface temperature. Based on these considerations, the solar energy gain of the green roof reduces up to 90% compared with conventional roof (Getter and Rowe, 2006, 1279). In addition, the ability of green roofs to reduce the temperature is the strongest in summer and weakest in winter (Shafique et al, 2018, 765). For instance, in a study about the heat oscillations of green roof and traditional black roof, the black one reaches 60^{o}C in summer months, while the green roof's heat oscillation is around 30^{o}C. Similarly, during winter, the peak heat oscillation of the green roof is approximately 10^{o}C while the heat oscillation of black membrane changes between 30^{o}C and 40^{o}C (Susca et al, 2011, 2124).

3.4.1.3 Enhancement of Biodiversity

Biological diversity or biodiversity means species richness which refers to the total number of different species in a defined area (Latty, 2016, 108). The green roof can support the formation of more diverse fauna and flora by means of its minerals, nutrients and organic elements such as water (Ngan, 2004, 3).

Green roofs involve a lot of nutrients and resources to support animals and microorganisms. Especially extensive green roofs offer undisturbed habitat for microorganisms because of the inaccessibility of the green roof (Getter and Rowe, 2006, 1279). Consequently, green roofs create habitats for both invertebrates such as insects, bees, butterflies, moths and earthworms and vertebrates such as birds. This function of green roofs serves as a bridge between fragmented areas in the city by increasing biodiversity (Ngan, 2004, 3). The level of biodiversity depends on the conditions like thickness and materials of substrate. For example, earthworms need deeper substrate to protect from the high temperatures in summer (Brenneisen, 2006, 29).

Ford Motor Company (almost 43,000 m^2) has one of the world's largest green roof (Figure 3.28), where 2 bird species, 7 spider species, and 29 insect species were identified within the first two years of its establishment period (Coffman and Davis, 2005 cited in Getter and Rowe, 2006).

Also, well designed green roofs contribute to the creation of habitats for the endangered or rare species (Sutton, 2015, 198). In Basel, Switzerland a research program about the biodiversity of the green roof was established to compensate for ecological damage. The research found 13 of 79 beetle species were classified endangered while the 7 of the total 40 spider species was identified endangered (Brenneisen, 2006, 28). Figure 3.29 shows a biodiverse green roof on Main Exhibition Hall in Basel.

Figure 3.28 Green roof on Ford Motor Company
(https://www.greenroofs.com/projects/ford-motor-companys-river-rouge-truck-plant/)
[Accessed: 11.05.2021]

Figure 3.29 Green roof on Main Exhibition Hall in Basel
(https://jim-labbe.travellerspoint.com/s3/)
[Accessed: 11.05.2021]

Due to the harsh environmental conditions on the roofs such as drought and temperature fluctuations, the plant types used in green roofs are limited (Sutton, 2015, 194). Generally, sedum species are used for the green roof because they store excess water and limit the transpiration to tolerate drought conditions (Vijayaraghavan, 2016, 744). In addition to the sedum species, native species that are already adapted to the local climate conditions can be used in order to maximize the efficiency of the green roofs (Latty, 2016, 107; Vijayaraghavan, 2016, 745). If a mixture including local plants is provided, green roofs provide better ecosystem services and provide better insulation. If a mixture of local plants and sedums are used on the green roofs, they provide greater ecosystem services and better insulation (Sutton, 2015, 194). The green roof on the Wollishofen water plant have been covered by some native annual and perennial herbs when the roof was constructed in 1914. 90 years later, the roof consisted of 175 plant and 9 orchid species which were defined as endangered (Brenneisen, 2006, 29).

3.4.1.4 Mitigation of Air Pollution

Highly developed urban areas are mostly exposed to air pollution because of the existence of industry and heavy traffic (Shafique et al, 2018, 765). The most serious components of air pollution are ozone and particulate matter which damage human health by triggering respiratory and cardiovascular illnesses (Bottalico et al, 2016).

Plants are capable of filtering and absorbing air pollutants by means of direct and indirect processes. For example, consuming gaseous pollutants by stomata is a direct process while regulation of microclimate is defined as an indirect process (Vijayaraghavan, 2016, 744). Trees are known as the most effective vegetation type in mitigating air pollution thanks to the large leaf surface area (Sutton, 2015, 222). Figure 3.30 shows the process of air filtration of green roof. For this reason, intensive green roofs are more effective in mitigating air pollutants because of containing shrubs and trees. However, extensive green roofs still play a complementary role in improving air quality (Rowe, 2011, 2102). A 1,000 m^2 green roof can remove approximately 160-220 kg of dust per year result in enhancing environmental quality (Shafique et al, 2018).

Figure 3.30 Process of air filtration of green roof
(Ajuntament de Barcelona, 2015)

A study performed in Chicago shows that a 19.8 ha green roof can capture around 1675 kg air pollutants annually with particulate matter (PM_{10}) and ozone (O_3) accounting for 14% and 52% of the total respectively (Yang et al, 2008 cited in Vijayaraghavan, 2016). Moreover, other gaseous pollutants in the atmosphere such as derivatives of NO_2 and SO_2 are filtered by green roofs. According to a research project conducted in Singapore, after the implementation of the green roof, the level of SO_2 emissions are reduced by 37% (Tan and Sia, 2005).

Besides, CO_2 is one of the most important factors that play a crucial role in both decreasing air quality and accelerating global warming. Green roofs have two ways to reduce the amount of CO_2 in the atmosphere. Firstly, plants have the ability to sequester CO_2 by photosynthesis. Thus, the amount of CO_2 decreases in the atmosphere while the amount of O_2 increases. Green roofs reduce fossil fuel consumption through the reduction of the energy consumption of buildings. As a result, the level of CO_2 in the atmosphere is decreased (Rowe, 2011, 2103).

The pollution abatement potential of the green roof depends on various parameters related to plants on it such as stomatal conductance, drought resistance, leaf surface area. Although green roofs cannot replace trees in mitigating air pollution, they are useful and beneficial in reducing environmental discomfort (Sutton, 2015).

3.4.1.5 Noise Reduction

Natural areas like soil and plants absorb the sound waves whereas the reflection of the sound waves from the concrete surfaces increases the noise in the cities (Getter and Rowe, 2006, 1280). Green roof attenuates the noise both indoor and outdoor environments through the substrate and vegetation layers. Thus, it provides great benefits for the settlements which is located close to the airports or highways. (Ngan, 2004, 4).

Compared to traditional concrete roofs, green roofs can reduce the frequency of noise by 10 dB to 20 dB (Shafique et al, 2018, 766). The sound absorption coefficient significantly depends on the substrate depth, plant characteristics and moisture content. The absorption coefficients of green roofs with different substrate depths which range from 50 mm to 200 mm range between 0.20 and 0.65 (Connelly and Hodgson, 2015). For example, Frankfurt Airport, which has a green roof with 10cm depth, can reduce noise levels by 5 dB (Dunnet and Kingsbury, 2004 cited in Getter and Rowe, 2006).

Also, the efficiency of sound insulation of green roofs is increased in low rise buildings because the direct interaction between urban noises and green surfaces are more effective in enhancing the absorption ability (Vijayaraghavan, 2016, 743).

3.4.2 Economic Benefits

Green roofs are one of the most suitable nature-based solutions for cities because idle rooftops are converted into green areas without the need for additional ground space. Compared to other green infrastructures, green roof provides more monetary value at both public and individual levels (Feng and Hewage, 2018, 307). Although the initial cost of the green roof is high, after the completion of the installation phase, payback period is approximately 55 months which is included both personal costs and entire benefits (Bianchini and Hewage, 2012, 158).

The longevity of roof membrane, reduction of energy consumption are direct economic benefits of green roof. Moreover, green roof contribute to the economy indirectly by managing stormwater, reducing urban heat island and enhancing the air quality. It is quite difficult to measure the monetary value of these indirect benefits of green roof (Shafique et al, 2018, 766).

3.4.2.1 Longevity of Roof Membrane

Green roof protects the roof membrane against ultraviolet radiation, extreme heat and diurnal fluctuations (Shafique et al, 2018, 766). It prevents the corrosion caused by temperature fluctuations through vegetation and substrate layers. For this reason, green roof lengthens the life span of the roof membrane (Vijayaraghavan, 2016, 744). Feng and Hewage (2018) assert that the life span of the roof membrane in the conventional roof may change between 10 and 30 years while the life span of the roof membrane increases up to 50 years with the green roof.

While the daily temperature fluctuation of a green roof is only 3°C, the fluctuation of a non-green roof can reach 50°C (Liu and Baskaran, 2003 cited in Getter and Rowe, 2006, 1279). A study performed in Ottawa revealed that on the day when the outside temperature is 35°C, the temperature of the conventional gravel ballasted roof have reached 70°C, while the temperature of the green roof varies between 25°C to 30°C (Ngan, 2004, 4).

3.4.2.2 Energy Conservation

One of the direct economic benefits provided by the green roof is that it provides energy savings to the building where it is located. It helps saving energy in two ways: Firstly, it reduces energy consumption of the buildings by providing shading and insulation to them (Getter and Rowe, 2006, 1279). Thus, the energy costs needed for cooling in summer and heating in winter are reduced. According to a study conducted in Canada, about 2,980 m^2 green roofs on the one-story building save about 10% of total heating and 6% of total cooling energy consumption respectively (U.S. Environmental Protection Agency, 2008, 6).

Secondly, the contribution of the green roof to the mitigation of the surface temperature also reduces the heat transfer among the roof and the rooms under the roof. It directly contributes to the improvement of the thermal performance of the buildings and indoor thermal comfort. For instance, after the installation of the green roof on Chicago City Hall, the total energy savings including both cooling and heating is estimated $4000 annually (Getter and Rowe, 2006, 1279).

The reduction in annual energy load can vary between 1% and 40% depending on various criteria such as types of buildings, green roof design and climatic zones. The affirmative impacts of green roofs in non-insulated buildings can be observed more clearly than in insulated ones (Santamouris, 2014, 684).

Related to the green roof design, the type of plants and content of the substrate layer are important factors to get maximum energy savings from the green roof (Vijayaraghavan, 2016, 742). Plant selection is crucial for shading effect because plants which have high leaf area index create larger shading areas. In addition to the plant selection, the depth and reflectivity of the substrate layer have importance to decrease the energy amount on the roof (Shafique et al, 2018, 765).

Moreover, climatic zones affect the performance of green roofs which helps to increase energy savings correspondingly. The study which comprises nine cities in different climate regions demonstrates that green roofs show greater performance in reducing the surface temperature in driest and hottest climates. The reduction of the surface temperature can also decrease the energy demands of the building which has a green roof quite significantly (Alexandri and Jones, 2008 cited in Shafique et al, 2018, 765).

3.4.2.3 Enhancement of Property Value

It is known that natural landscapes such as forest, wetlands increase the market value of property (Austin, 2014, 88; Benedict and McMahon, 2012, 53). Although the green roof cannot replace these natural elements, it has the potential to increase the property value of the building which it is located on by providing many direct and indirect benefits (Feng and Hewage, 2018, 309; Shafique et al, 2018, 766).

Saving the energy and extending the life of the roof membrane are direct benefits that serve additional private advantages to the owners. These improvements related to the building lengthen also the life of the building and increase its property value (Dixon and Wilkinson, 2016, 2). According to the study of Bianchini and Hewage

(2018, 154) the value of property increases from \$132/m^2 to \$174m^2 for extensive green roof.

Although some factors such as location and proximity to public services are more important in determining the total value of the property, indirect benefits of the green roof such as reduction of noise, improvement of air quality, mitigation of surface temperature also provide additional advantages for both the property and the public. (Bianchini and Hewage, 2012, 154). For example, Germany has split wastewater fee system that depends on the size of the impervious surface on the property to manage the stormwater runoff. Also, the property owner is obliged to pay this fee every year. Thanks to the green roof, the amount of fee can be decreased (Ngan, 2004, 20).

Installing a green roof on the buildings contributes to sustainability, as it provides a bonus point for the building certification system such as LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method). These systems have been established to mitigate the negative impacts of the buildings on the environment (Dixon and Wilkinson, 2016, 6; Feng and Hewage, 2018, 309). Thus, the fact that buildings have this certificate not only reduces environmental impacts but also increases the building value and reduces vacancies in the building (Getter and Rowe, 2006, 1280).

3.4.3 Social Benefits

Green roofs create a visually balancing and relaxing environment in urban areas, which lack adequate amount of green spaces, and which has mainly asphalt and concrete surfaces. The environmental image created by green roofs has positive psychological and physical effects on people, yet not as much as trees or urban parks and green spaces on the ground (Ngan, 2004, 5). It not only increases the property value and preferability of the building, but also creates an attraction for the residents (Bianchini and Hewage, 2012, 154-155). These social benefits created by the green roof are classified as aesthetic and amenity values, health and therapeutic values and the urban farming.

3.4.3.1 Aesthetic and Amenity Value

Because of the limited space at ground level, green areas do not increase in proportion to the growing population. Green spaces are needed where people can spend time and have fun. Green roofs provide more innovative approach to urban planning by increasing aesthetic and amenity values like forests, wetlands, and grasslands. Particularly, the intensive green roof not only offers people a recreation area but also creates a space for farming activities, thanks to its accessibility (Greater London Authority, 2008, 19). Intensive green roof is an opportunity to create community gardens and recreation spaces in more compact urban form with less space in the ground level.

The Gathering Place in Denver (Figure 3.31 and 3.32) is daytime drop-in center for homeless and indigent women, transgender persons and their children. The roof of the Gathering Place designed as a playground garden with fruits, vegetables and herbs which are used in daily kitchen. Therefore, visiting women and their children can spend time to help planting and harvesting (Tolderlund, n.d.).

Figure 3.31 Green roof of the Gathering Place

(https://leilatolderlund.com/project/urbanplaygarden/) [Accessed: 15.05.2021]

Figure 3.32 Vegetables on the Gathering Place Green Roof

(https://leilatolderlund.com/project/urbanplaygarden/) [Accessed: 15.05.2021]

On the other hand, extensive green roofs generally provide a pleasant view for the surrounding buildings since they are inaccessible to the public (Vijayaraghavan, 2016, 744). Despite their inaccessibility, extensive green roofs play an important role in linking the spaces between buildings and ensuring the continuity of the open spaces (Weiler and Scholz-Barth, 2009, 65).

Weiler and Scholz-Barth (2009, 65) note that "the significance of living green roofs and landscapes over structure in influencing human perception is that even from an interior perspective, the positive visual or psychological experience of exterior spaces can be extended and heightened by their use".

3.4.3.2 Health and Therapeutic Value

It has been proven by many studies that green landscapes make positive contributions to both psychological and physical health of people (Tzoulas et al, 2007, 170; Molla, 2015, 91; Austin, 2014, 15).

Viewing green plants and nature has positive health effects, such as reducing stress, lowering blood pressure, releasing muscle tension, and increasing positive feelings (Getter and Rowe, 2006, 1279). Also, it was found that in a workplace with a nature view such as trees and plants the workers catch fewer illnesses, get less stressed and have greater motivation than those who have not natural view (Kaplan and Talbot, 1988 cited in Aras, 2019, 489).

The ecological benefits of the green roof, explained in Section 3.3.1, also have positive impacts on human health. Reduction of noise and air pollution, mitigation of urban heat island and enhancement of biodiversity are the ecological benefits of green roof which also result in positive health outcome on humans.

Firstly, reduction of noise pollution creates favorable effects on the health of inhabitants (Shafique et al, 2018, 766). People, who are exposed to noise continuously, may have some problems such as hearing impairments, sleep disturbances and hypertension (Getter and Rowe, 2006, 1280). However, green roof provides people more livable and comfortable conditions by helping reduce the level of noise (Vijayaraghavan, 2016, 743).

Similarly, air pollution not only damages the environment but also harms human health. Some airborne particulates (PM_{10}) cause serious health problems such as bronchitis, respiratory diseases such as asthma even lung cancer (Austin, 2014, 21). As the green roof has the ability to ameliorate the poor air quality, it is one of the most effective means for combating these diseases and contributing to human health (Wilkinson and Torpy, 2016, 169).

Moreover, the urban heat island not only harms human health but also even cause human deaths. Many studies show the positive correlation between increased urban temperature and growing morbidity and mortality rates (Austin, 2014, 64; Norton et al, 2015, 127; Osmond and Irger, 2016, 39; Santamouris, 2014, 683). For example, it has been thought that heat waves have more dangerous effects on human lives than any other natural disaster in Australia (Nicholls et al, 2008 cited in Osmond and Irger, 2016, 39). Nonetheless, the green roof both reduces the health problems and offers the thermal comfort to the habitants around the green roof by alleviating the effects of urban heat island.

Compared to other ecological benefits of the green roof, the enhancement of biodiversity has more spiritual results on human health. Green roofs increase biodiversity and minimize the effects of habitat fragmentation by attracting wildlife (Weiler and Scholz-Barth, 2009, 129). It has been thought that species-rich ecosystems are more resilient to changes and they are more productive than the simpler ecosystems. Human health is positively affected, particularly in urban areas, in terms of psychological, cultural and other intangible benefits which can be obtained by contact with ecosystems (Tzoulas et al, 2007).

3.4.3.3 Urban Farming

Green roofs also provide inhabitants with opportunities for urban farming. Thus, society's self-reliance in producing different kinds of vegetables or fruits has increased while the security of food production has been provided (Shafique et al, 2018, 766).

Depending on the depth of the green roof, different types of vegetables and fruits can be grown on it. 20 cm depth of soil layer is enough to grow some fruits and vegetables such as strawberries, melons, lettuce, and eggplant. Even the extensive green roof with a depth of 15 cm is suitable for native herbs. On the contrary, some of the vegetables and fruits need to be grown on deeper soil layers such as tomatoes and blackberries (Zinco Green Roof, n.d.).

According to the regulation in Tokyo, 20% of rooftops of the buildings have to be allocated for greenery. Hence, some parts of the rooftops have been used as farming areas for production and cultivation of especially domestic foods of Japan such as rice. 130 m^2 roof area of Roppongi Hills (Figure 3.33) reserved for visitors to participate in the activities of planting and harvesting plants on it (Hui, 2011, 4). Figure 3.34 shows the rice field on Roppongi Hills Rooftop.

Figure 3.33 Roppongi Hills Rooftop Farm

Figure 3.34 Roppongi Hills Rice Field

(https://www.roppongihills.com/en/green/rooftop_garden/seasons/spring.html) [Accessed: 15.05.2020]

Thammasat University in Thailand has the largest urban rooftop farm in Asia. Unpredictable weather conditions lead to the flooding events which damage fertile agricultural lands. Also, most productive rice-paddles in Thailand have turned into the concrete cities because the urban sprawl. These are just a few of reasons why this green roof was built. This rooftop farm (Figure 3.35) not only is an outdoor classroom for academic staff and students but also is a social interaction and learning platform for society. The cascading form of the green roof provide absorb and collect rainwater to irrigation and future use.

7 m^2 of a total of 22 m^2 of green roof constitute the urban farming area. It consist of 16% herbs, 36% vegetables and 48% rice paddles. Almost 3,745 kg rice are harvested from the rooftop farm annually (Holmes, 2020).

Figure 3.35 Thammasat University Rooftop Farm
(https://archello.com/project/thammasat-urban-rooftop-farm-turf) [Accessed: 15.05.2020]

Table 3 Benefits of Green Roof

Environmental	Social	Economic
Stormwater Management	Aesthetic and Amenity Value	Longevity of Roof Membrane
Mitigation of Urban Heat Island	Health and Therapeutic Value	Energy Conservation
Enhancement of Biodiversity	Urban Farming	Enhancement of Property Value
Mitigation of Air Pollution		
Noise Reduction		

3.5 Some Examples of Green Roofs

3.5.1 Kampung Admiralty

It was designed in Singapore as both a public housing project and a community hub for encouragement of multigenerational interaction and completed in 2018. The aim of the project was to provide elderly people with strong green infrastructure for social, educational, health and well-being. In addition to the social cohesion, the project contribute to the environmental sustainability. The architects designed the vegetation as an integral part of the construction. Thereby, they aimed at ensuring the thermal comfort and reducing the urban noise. Over 610 trees and 80,000 shrubs were planted on the approximately 3600 m^2 roof area. It also accommodates 18 species of fruit trees which are grown locally (Samant, 2019). The construction also consisted of many sustainable elements such as bio-swales and rain gardens. Also, a bio-retention basin enables to harvest and purify the stormwater so that it can be reused for plant irrigation (Ramboll Studio Dreiseitl, 2020). Figure 3.36, 3.37 and 3.38 belongs to the green roof on Kampung Admiralty.

Figure 3.36 Intensive green roof on Kampung Admiralty
(https://www.archipanic.com/kampung-admiralty/) [Accessed: 10.12.2020]

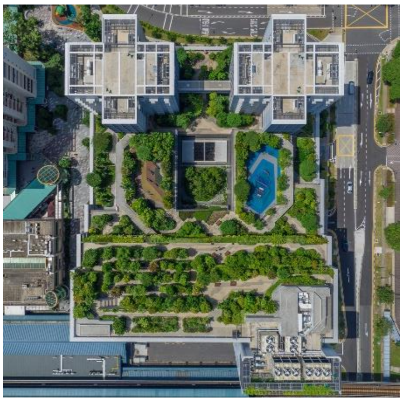

Figure 3.37 Top view of Kampung Admiralty

Figure 3.38 Vegetation in Kampung Admiralty

(https://www.archipanic.com/kampung-admiralty/) [Accessed: 10.12.2020]

3.5.2 Le Cordon Bleu Paris

Le Cordon Bleu is an international cooking school that has a 1011 m^2 roof garden constructed in 2016. It was designed on the flat roof to grow required crop plants such as vegetables, fruits, and herbs. Successful cultivation of these plants depends on the regular irrigation. In addition to irrigation, sunshine duration is also important factor to affect the plant growth. Because of the height of building, plants are exposed to both sunlight and the reflection of light from the glass of surrounding buildings. Therefore, sunniest spots were analyzed before the installation. Furthermore, there are 52 planting beds on the roof while the depth of growing medium is nearly 23cm in these beds. The depth around the planting beds is about 8 cm which are designed as pathways. The roof accommodate 4 beehives which produce 50 kg honey once a year and an insect hotel which help to the pollination. (Zinco Green Roof, 2020). Figure 3.39 and 3.40 shows the green roof on Le Cordon Bleu in Paris.

Figure 3.39 Top view of Le Cordon Bleu
(https://zinco-greenroof.com/press-release/le-cordon-bleu-paris) [Accessed: 10.12.2020]

Figure 3.40 Planting beds on green roof
(https://zinco-greenroof.com/press-release/le-cordon-bleu-paris) [Accessed: 10.12.2020]

3.5.3 Chicago City Hall

The driving force behind the implication of the green roof on Chicago City Hall (Figure 3.41, 3.42 and 3.43) is to reduce the urban heat island effect and enhance the air quality. The semi-intensive green roof which has 15 cm growing medium was completed in 2001. Approximately 3530 m^2 green roof consist of more than 150 plant species including vines, shrubs and trees. Most of them native to the Chicago climate are resistant to the wind and arid. Although, plants have ability to survive drought conditions, drip irrigation system was implemented in the roof to provide water during long dry periods (Dvorak, 2015). According to maintenance plan, weeding is necessary bi-weekly during the initial period. It is estimated that the Chicago City could save around $4000 U.S dollars annually with the green roof (Laberge 2003 cited in Dvorak, 2009)

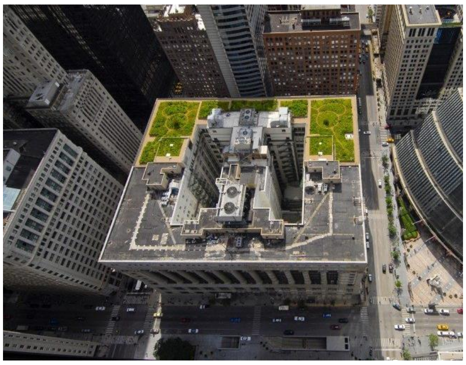

Figure 3.41 Top view of City Hall

(https://www.nps.gov/tps/sustainability/new-technology/green-roofs/summary.htm) [Accessed: 10.12.2020]

Figure 3.42 Vegetation on green roof

(https://tclf.org/landscapes/city-chicago-city-hall-green-roof) [Accessed: 10.12.2020]

Figure 3.43 Green roof in Chicago City Hall

(https://tclf.org/landscapes/city-chicago-city-hall-green-roof) [Accessed: 10.12.2020]

3.5.4 Vancouver Convention Center

Vancouver Convention Center in Canada is another example for semi-intensive type of green roof which was completed in 2009. The green roof installed on the sloped roof which varies between 3% and 56% (GreenRoofs WebSite, 2020). Moreover the roof which was designed in order to receive LEED certification covers nearly 2.5 ha area with different layers. Besides, the roof which has a nearly 15cm growing medium is inaccessible to visit. It gets inspired by coastal grassland flora including 24 species of local forbs and grasses such as fescues, onions, and stonecrop. These plants adapt to the climate so they do not need supplemental watering except during drought periods. The wastewater used in the convention center is treated to irrigate the plants during dry periods (Dvorak, 2015, 399).

Figure 3.45 Aerial view of Vancouver Convention Center
(https://inhabitat.com/spectacular-green-roof-tops-vancouvers-double-leed-platinum-convention-center/) [Accessed: 10.12.2020]

Figure 3.44 Vegetation on Vancouver Convention Center
(https://www.vancouverconventioncentre.com/news/media-release-annual-mowing-of-living-roof) [Accessed: 10.12.2020]

Figure 3.46 Green roof in Vancouver Convention
(http://greenbuildingreview.com/vancouver-convention-centre-is-officially-the-worlds-greenest-convention-centre/) [Accessed: 10.12.2020]

3.5.5 Küçükçekmece City Hall

Küçükçekmece City Hall which is the first BREEAM certified public administration building in Turkey is completed in 2014. Hence, the main purpose of the implementation of the green roof is to receive BREEAM certification. The extensive green roof installed on an area of approximately 3600 m^2 has a growing medium of 15 cm. The whole roof covers various types of sedum excluding the paths. Moreover, the stormwater is harvested to use for the irrigation of the green spaces including the green roof. Also, heat and sound insulation was provided building through the green roof (Yeşil Bina Dergisi, 2014, 43). Figure 3.47 and 3.48 shows green roof on Küçükçekmece City Hall.

Figure 3.47 Aerial view of Küçükçekmece City Hall
(https://www.ekoyapidergisi.org/3215-kucukcekmece-belediyesinde-btm-yesil-cati-sistemleri-kullanildi.html) [Accessed: 10.12.2020]

Figure 3.48 Vegetation on Küçükçekmece City Hall
(http://greenbuildingreview.com/vancouver-convention-centre-is-officially-the-worlds-greenest-convention-centre/) [Accessed: 10.12.2020]

3.5.6 Schiphol International Airport

The government of Netherlands wanted to adopt a sustainable approach for the concrete and other impervious surfaces. For this reason, it was decided that the green roof was implemented in Schiphol Airport because airports occupy huge amounts of impervious spaces such as runways and parking and many flat roofed buildings. Three buildings in the airport have an extensive green roof with 13.330 m^2 total area. The growing medium and vegetation are designed not to attract the attention of birds in order to avoid bird strikes. Therefore, sedum types were used instead of plants that would attract them, such as fruits, seeds and flowers. The depth of the 4 cm growing medium is enough to survive of sedums. Moreover, it is not allowed people to visit the roofs because of the security restrictions (Cantor, 2008, 130). Figure 3.49 and 3.50 shows the extensive green roof on Schiphol Airport.

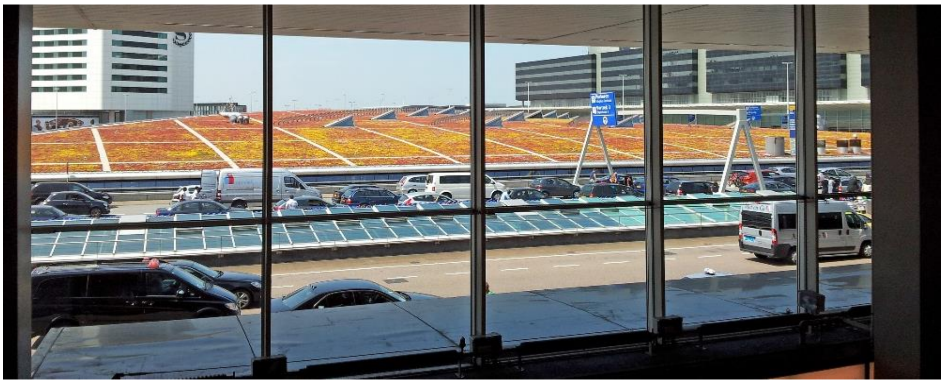

Figure 3.49 Green roof in Schiphol Airport

Figure 3.50 Top view of Schiphol Airport
(https://zinco-greenroof.com/references/airport-schiphol-amsterdam) [Accessed: 10.12.2020]

3.5.7 Piri Reis University

Piri Reis University is the first Turkey's first BREEAM certified training campus. One of the actions carried out to gain the certificate was the green roof installation on a total of 3,150 m^2 roof area. 178,000 sedums have been used to cover the roof because they require minimum water and maintenance. Thus, the cost of heating and cooling of the building have been minimized. With the rain sensors included in the green roof, the irrigation system is automatically disabled when it rains. Hence, not only the water is saved but also excess water is harvested in a tank and purified to be used for irrigation (Ekoyapı Dergisi, 2015). Figure 3.51 and 3.52 shows the extensive green roof on Piri Reis University from different perspectives.

Figure 3.51 Aerial view of Piri Reis University
(https://www.karaoglu.com.tr/referanslarimiz/piri-reis-universitesi/) [Accessed: 10.12.2020]

Figure 3.52 Green roof on Piri Reis University
(https://www.arkiv.com.tr/proje/piri-reis-universitesi/2167) [Accessed: 10.12.2020]

3.5.8 Garanti Bank Technology Campus

The building in Garanti Bank Technology Campus was completed in the 2018 in İstanbul. Within the scope of sustainable practices to obtain LEED certification, extensive green roof was implemented on the sloped and round roof. It is the first green roof example which installed on a round, amorphous and high pitched surface in Turkey (Yeşil Bina Dergisi, 2020). The total surface area of 6 hills, whose slopes are nearly 73%, is about 8,000 m^2. 10 cm depth growing medium and sedum carpets were used. Spaces with little light were determined by performing an annual solar simulation. As a result, sedum plants that adapted these conditions were placed in these spaces. Different types of anchors were used to prevent the slipping of the growing medium and vegetation because of the high slope of the roof (Bonfil, 2018). Figure 3.53 and 3.54 shows the green roof on Garanti Bank Technology Campus.

Figure 3.53 Green roof on Garanti Bank Technology Campus
(http://www.arkiv.com.tr/proje/garanti-teknoloji-kampusu/4432) [Accessed: 10.12.2020]

Figure 3.54 Round green roof on a hill
(http://www.arkiv.com.tr/proje/garanti-teknoloji-kampusu/4432) [Accessed: 10.12.2020]

CHAPTER 4

GREEN ROOF IMPLEMENTATIONS AT CITY AND NEIGHBORHOOD SCALES

"One of the first conditions of happiness is that the link between man and nature shall not be broken."

Leo Tolstoy

Green roofs seem to be mostly implemented at building scale, still, there are examples at larger spatial scales ranging from settlement to neighborhood scales. In some cases, green roof implementations are included in different policies, plans and legislation, and they are considered as elements of the green infrastructure in cities. This chapter discusses the tools for green roof implementations at urban and neighborhood scales. It elaborates the purpose of these tools, and whether they contribute to the green infrastructure with reference to different world examples. It also examines the main actors of the green roof implementations.

4.1 Green Roof Implementations at City Scale

4.1.1 Barcelona

Barcelona City Council made a commitment at COP21 held in Paris to combat the negative effects of climate change. There are two main goals of this commitment; first to reduce CO2 emissions, and second to increase the quality and quantity of green spaces. With regard to the mitigation and adaptation efforts, Barcelona Green Infrastructure and Biodiversity Plan, and Guide to Living Terraces and Green Roofs were prepared by Barcelona City Council Barcelona. It aims to reach 34,100 m^2 of green roofs, walls and façades by 2030 (Ajuntament de Barcelona, 2018a).

It is quite difficult to find green spaces in urban built-up areas in Barcelona, because it is a crowded and dense city. The ratio of green space per inhabitant is close to the 7 m^2. However, in some districts, green space per capita is below the standards. For example, in Eixample green area per resident is 1.85 m^2, while this amount is 3.15 m^2 in Gràcia. The World Health Organization states the minimum urban green space per person as 9 m^2 (Ajuntament de Barcelona, 2017, 5). According to the commitment, city's green spaces per capita will be increased by 1 m^2 by 2030. This amount is equal to 160 ha of new green spaces (Ajuntament de Barcelona, 2017, 29).

For this reason, the City Council of Barcelona made an analysis about the potential of existing green spaces to explore different ecosystem services and turn them into functional greenery. After the analysis, they determined the three major goals as 1) improving the urban green infrastructure to utilize the ecosystem services, 2) increasing green infrastructure for public health, and 3) lastly promoting the public participant in increasing green spaces. Projects carried out within the scope of these goals aim at creating green spaces that are evolving as a system by focusing on the quality of green spaces rather than the quantity of them (Ajuntament de Barcelona, 2017, 6).

As described in the first chapter, this definition also refers to green infrastructure. One of the best strategies for a compact city like Barcelona, which has inadequate green spaces in its urban fabric, is increasing the green surface by installing the green roofs and roof gardens on rooftops of both existing and new buildings (Ajuntament de Barcelona, 2017, 29). This is because 69% of the total roof area in the city is composed of flat and slightly inclined roofs, which is 1,764.4 ha (Ajuntament de Barcelona, 2018a, 82). An incentive program was developed not only to create green roofs on municipal buildings, but also to facilitate the installation of green roofs on public and private buildings. Figure 4.1 shows the distribution of green roofs in Barcelona in 2012.

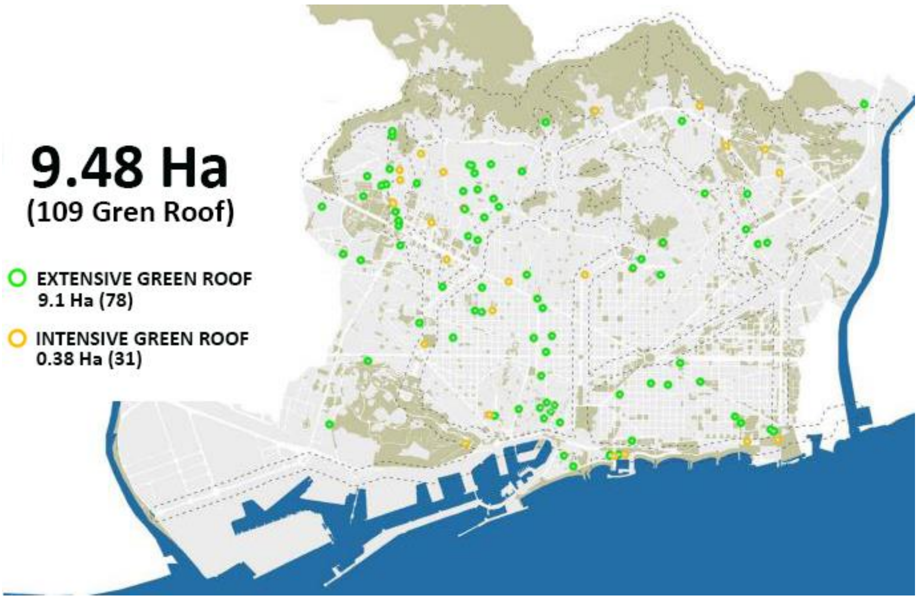

Figure 4.1 Green roof distribution in Barcelona in 2012
(https://gobernanzalocal.files.wordpress.com/2012/10/c-verdes_bcnecologia.pdf) [Accessed: 16.05.2020]

Green Roof Competition

In June 2017, Barcelona City Council organized a Green Roof Competition to encourage the installation of new green roofs. 10 of the submitted projects were rewarded.

One of the winning green roof projects is in the street of Balcells which includes allotment tables (Figure 4.2) and several horticultural species (Figure 4.3). The fertilizer need of vegetation on the green roof is obtained from compost heaps, while the water needs are met by stormwater collected in a tank by drip irrigation method. The energy that enables pumping of water is obtained from solar panels. It also promotes biodiversity by accommodating a wide variety of nests of birds, insect hotels, and shelters for bats (Ajuntament de Barcelona, n.d.).

Figure 4.2 Green roof in the street of Balcells

Figure 4.3 Allotment tables on the green roof

(https://ajuntament.barcelona.cat/ecologiaurbana/sites/default/files/noind/10propostesguanyadorescobertes.pdf) [Accessed: 28.12.2020]

Figure 4.4 Aerial View of Green Roof in the street of Balcell

(Google Earth, 2019) [Accessed: 15.05.2020]

Another winning green roof project is located on the nearly 1,100 m^2 roof of TEB Cooperative Group (Figure 4.5) which was designed to provide social integration for the people mentally disabled. The roof is divided into three parts. The first part is covered with different sedum types. While the second part of the roof is designed as a Mediterranean Garden (Figure 4.7) which promotes pollinators such as bees and insects, the last one is a cultivation space for the enjoyment of people (Figure 4.6) (Ajuntament de Barcelona, n.d.).

Figure 4.5 Aerial View of Green roof on TEB building
(Google Earth, 2020) [Accessed: 15.05.2020]

Figure 4.6 Mediterranean garden on the green roof of TEB building
(https://ajuntament.barcelona.cat/ecologiaurbana/sites/default/files/noind/10propostesguanyadorescobertes.pdf) [Accessed: 28.12.2020]

Figure 4.7 Cultivation spaces and solar panels on the green roof of TEB building
(https://ajuntament.barcelona.cat/ecologiaurbana/sites/default/files/noind/10propostesguanyadorescobertes.pdf) [Accessed: 28.12.2020]

Thanks to the ten winning projects, the amount of greenery in the city increased by 5,500 m^2, while 217 m^2 solar panels were installed on the green roofs. Not only 2 windmills and 4 rainwater collection facilities were installed on these green roofs, but also wildlife supporting elements such as bird boxes, insect hotels, and ponds for amphibians were created in order to improve biodiversity (Ajuntament de Barcelona, n.d.).

Natural Sciences Museum of Barcelona

It is an experimental roof garden that fosters the research and investigation of green roof (Figure 4.8 and Figure 4.9). Therefore, animal and plant species on this roof are monitored to determine the most favorable species for green roofs that will be implemented thereafter. 7,100 m^2 of the total roof area of 14.000 m^2 is covered with a green roof (Museu de Ciències Naturals de Barcelona, n.d.). Native species were used in the roof to create natural ecosystem and allow plants to adapt more easily because the museum is close to the sea and in the windy location (Ajuntament de Barcelona, 2018b).

Figure 4.8 Aerial view of green roof on Natural History Museum

(Google Earth, 2020) [Accessed: 15.05.2020]

Moreover, because of the limited load capacity of the building, herbaceous plants and thin growing medium layer was chosen in the design of green roof. It includes several plant zones which are Mediterranean meadow, bulbous plants, salt-tolerant annual plants, Barcelona’s annual flower plants and marshland (Figure 4.10). In addition to the plant diversity, a number of permanent ponds and wetland areas were implemented on the roof (Figure 4.11). The roof is accessible to visitors at certain times of the day (Museu de Ciències Naturals de Barcelona, n.d.).

Figure 4.9 Green roof on Natural History Museum

Figure 4.10 Plant diversity on the green roof

(https://elpais.com/espana/catalunya/2020-06-27/jardines-colgantes-de-barcelona.html) [Accessed: 28.12.2020]

Figure 4.11 Permanent Ponds and Wetland Areas on the Green Roof

(https://elpais.com/espana/catalunya/2020-06-27/jardines-colgantes-de-barcelona.html) [Accessed: 28.12.2020]

Tools for Green Roof Implementations

Although there is no specific legal framework about green roofs in Barcelona, there are several legal instruments which deal with the issues related to the implementation of the green roofs like Law 22 / 1983 on the Protection of the Atmospheric Environment, Decree 21/2006 on eco-efficiency in buildings. These instruments can be the responsibility of different boundaries of authority such as international, national, regional (Ajuntament de Barcelona, 2014). For example, COP21 is an international conference while Barcelona Green Infrastructure and Biodiversity Plan is a nationwide document. Similarly, Barcelona City Council does not have any subsidy program for encouraging green roofs. However, the City Council provides financial aid for the rehabilitation of the roofs of both residential and industrial buildings.

In addition to these indirect tools, the most constructive instrument is Barcelona Green Infrastructure and Biodiversity Plan. The greater part of the actions related to the green roof were implemented within the scope of this plan (Ajuntament de Barcelona, 2014). For example, the competition was arranged in pursuant of this plan. All these efforts resulted in a total 169 green rooftop implementations recorded between 2014 and 2016. Furthermore, approximately 22,000 m^2 green roof will be expected to be installed in ten years period between 2020 and 2030 within the program (Ajuntament de Barcelona, 2017, 38).

Moreover, in April 2021, Barcelona City Council announced that 33 projects get through to the next stage to win the second green roof competition. It is expected that the winner projects will be announced during 2021, and the construction of the green roofs will be completed in 2022.

As a result, the city, which has a dense urban texture, adopted a holistic approach by handling the green roof as a component of the urban green infrastructure to solve the scarcity of green space. Even considering the dense urban fabric of Barcelona, it can be said that the most effective tool for increasing the amount of green space is a green roof. In the Barcelona case, City Council organizes the competition and promotes the green roof implementations so it is mostly the main actor. However, citizens from all strata can participate in the competition while experts assist in the evaluation of the projects.

Barcelona has implemented green roofs on municipality buildings in the first phase and organized competitions to raise awareness in the city in the scope of Barcelona Green Infrastructure and Biodiversity Plan. Also, creating an experimental green roof and studying different types of local vegetation is an important step to increase the number of reliable and well-informed manufacturers and suppliers in the city.

As a result of these efforts, the amount of green space per capita is expected to increase. Planned applications of the next periods and the second green roof competition can be considered necessary actions for adapting to climate change in the long-term period.

4.1.2 Toronto

Toronto is one of the C40 Cities, which is Climate Leadership Group, so almost 90% of Torontonians are worried about the climate change issues. Thus, the City of Toronto has been playing an active role in the fight against climate change for many years. The City of Toronto has aimed to achieve a sustainable city by providing strong community engagement and making well-thought-of strategies and plans (Mitrovic, 2010, 1).

TransformTO is one of the climate action strategies, which was approved by City Council in 2017 to reduce greenhouse gas emissions by setting short-term and long-term targets. More than 2,000 inhabitants participated to TransformTO with their ideas and actions. Toronto's targets about the reduction of greenhouse gas emissions are 30% by 2020, 65% by 2030 and net zero by 2050. All these targets are based on the 1990 levels of GHG emissions (City of Toronto, 2018).

Moreover, the Climate Change, Clean Air and Sustainable Energy Action Plan has been implemented in order to encourage the use of sustainable energy, and enhance poor air quality. There is an article in the plan regarding green roof: "*establish an Eco-Roofs Program, that sets a minimum target of 10% of the total industrial, commercial and institutional roofspace located in Toronto made more environmentally friendly by 2020"* (City of Toronto, 2007).

Many initiatives have been launched in order to achieve targets of this plan and TransformTO including the green roof strategy (Mitrovic, 2010, 1). These targets are the basis of the development of green roofs in Toronto.

Green roofs got involved on the environmental agenda of Toronto because they have numerous benefits such as the mitigation of stormwater runoff, urban heat island effect and especially conservation of energy. Also, it is playing an important role in reduction of GHG emissions in buildings (Loder, 2011, 5). Figure 4.12 shows green roof map of Toronto in 2013.

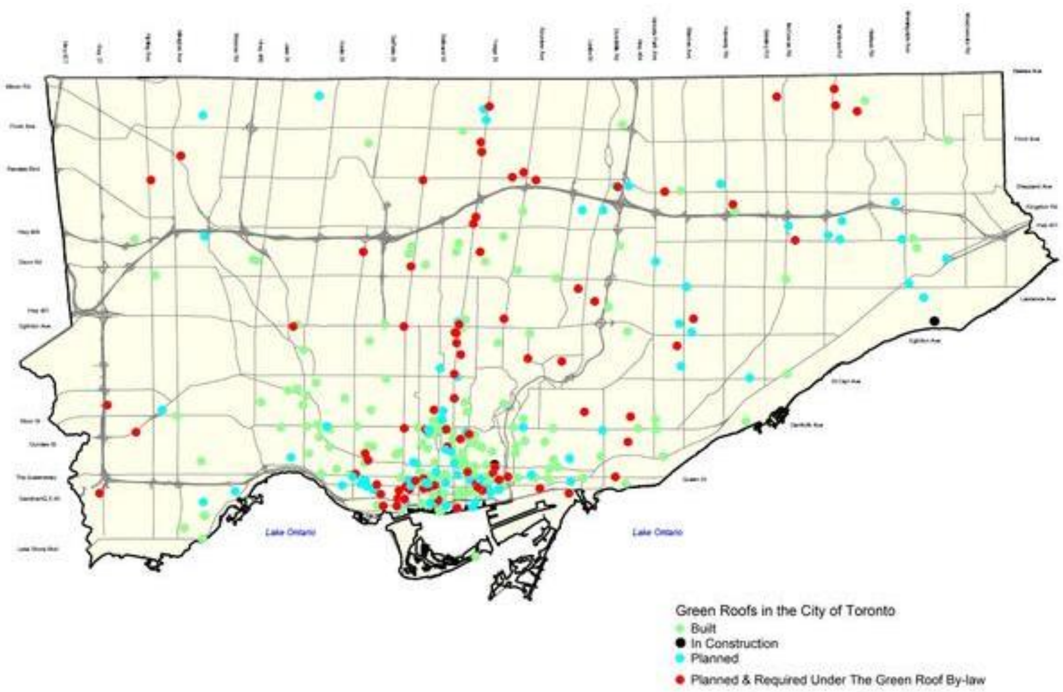

Figure 4.12 Green roof map of Toronto in 2013
(https://twitter.com/jen_keesmaat/status/402477653330247680) [Accessed: 15.05.2021]

City of Toronto consociated with Green Roofs for Healthy Cities (GRHC) and the National Research Council Canada (NRC) to implement an experimental green roof on the roof of City Hall (Figure 4.13), which is Toronto’s largest green roof accessible to public. Thanks to the 3,415 m^2 green roof (Figure 4.14), the potential benefits of the green roof have been monitored. Various regional species such as sedums, perennials, and grasses (Figure 4.15) have been used densely in the implementation of the green roof (City of Toronto, n.d.). The largest park in the city of Toronto is High Park is about 161 hectares. When we compare the largest green roof and park, we can see the huge difference. Although green roofs have many benefits, they do not compensate lack of green space in the ground.

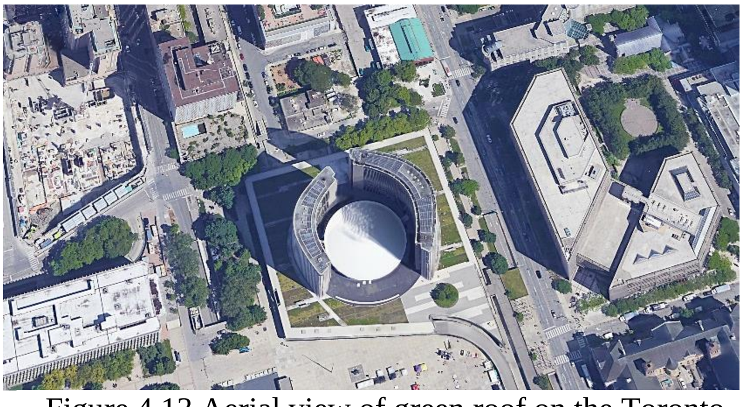

Figure 4.13 Aerial view of green roof on the Toronto City Hall

(Google Earth, 2019) [Accessed: 15.05.2020]

Figure 4.14 Green roof on the Toronto City Hall

(https://www.greenroofs.com/projects/nathan-phillips-square-toronto-city-hall-podium-green-roof/ [Accessed: 28.12.2020]

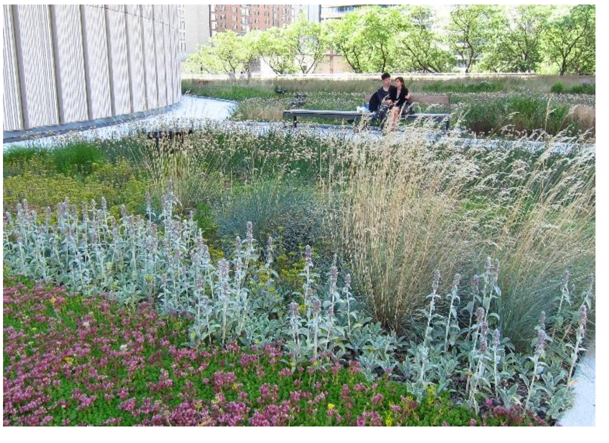

Figure 4.15 Different plant species on the green roof

(https://torontoimages.files.wordpress.com/2012/01/img_2212.jpg) [Accessed: 28.12.2020]

Although this initiative could not be used effectively for green roof campaigns, the report of “Making Green Roofs Happen” was presented in 2005 to define design principles of green roofs, challenges, and solutions in green roof implementations by Ryerson University (Loder, 2011, 45).

Toronto City Council adopted the report as a green roof strategy to encourage the installation of green roofs on citywide in 2006. The strategy included 4 important steps which are an incentive program, installation of green roofs on city buildings, utilization of policy tools and public education (City of Toronto, 2008).

1) The pilot incentive program was started in 2006 to encourage the implementation of green roofs funded by Toronto Water because of stormwater retention capacity of green roofs. 16 applicants benefited from the program which resulted in 3,000 m^2 green roof installation (City of Toronto, n.d.). In 2008, the program was renamed as eco-roof incentive program that particularly targets the constructions located where urban heat island and the amount of stormwater runoff is high. Therefore, stormwater measurement is required to apply for the program (Loder, 2011, 52). The program provided $100 per m^2 of green roof on both existing and new buildings. The city council also provides subsidy up to $1000 as a Structural Assessment Grant to retrofit the existing buildings (City of Toronto, n.d.).
2) City buildings such as agencies, commissions and boards have to be covered with green roof of at least 50% of available roof space within the scope of the green roof strategy. Gladstone Library and Toronto Botanical Gardens can be given as examples (City of Toronto, 2008, 2).

The extensive green roof which was installed on the Dembroski Centre (Figure 4.16) for Horticulture covers nearly 223 m^2 roof area. The sloped part of the roof consists of different types of sedum (Figure 4.17) while the flat part includes the wildflowers and native plants. The plants do not need irrigation due to the ability to survive drought conditions. The growing medium of the roof is composed of perlite, sand, peat, and recycled crushed brick in order to provide better anchorage and water retention capacity (Toronto Botanical Garden, n.d.).

Figure 4.16 Plant diversity on green roof

Figure 4.17 Green roof on Toronto Botanical Garden

(https://torontobotanicalgarden.ca/explore/the-green-roof/) [Accessed: 28.12.2020]

The green roof on the Gladstone Library (Figure 4.18 and Figure 4.19) has been installed on the 20% of the total roof area that equals approximately 176 m². The 15 cm growing medium which hosts a mix of meadow plants has been used on the extensive green roof such as grasses and fescues.

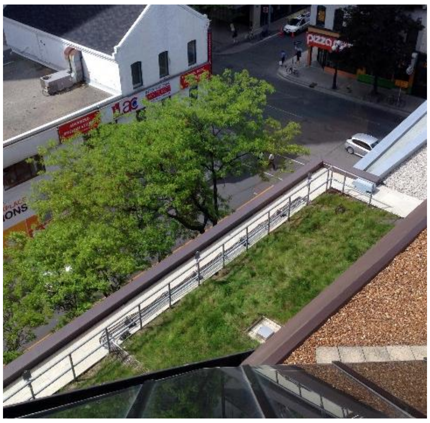

Figure 4.18 Green roof on the Gladstone Library

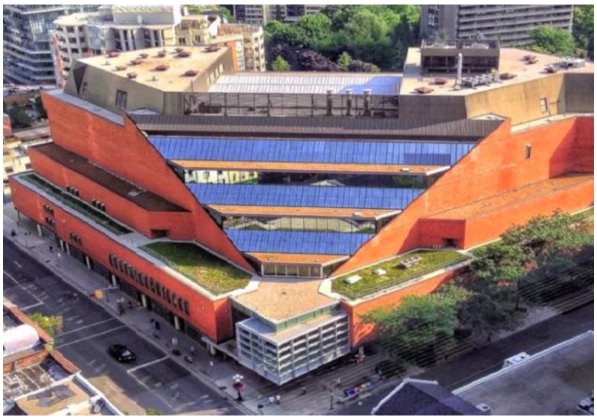

Figure 4.19 Aerial view of the green roof on the Gladstone Library

(https://torontobotanicalgarden.ca/explore/themed-gardens/greenroof/) [Accessed: 28.12.2020]

3) There are many other plans and documents to require the construction of green roofs: Environmental Plan, the Official Plan, the Wet Weather Flow Master Plan, Toronto Green Standard and Toronto Clean Air and Climate Change Action Plan (Loder, 2011, 48). In consideration of these documents the City Council adopted the Green Roof Bylaw under the authority of Section 108 of the City of Toronto Act in 2009 (Mitrovic, 2010, 2). Hence, a number of requirements for new buildings over 2,000 m^2 of gross floor area have come along this bylaw. An area varying between 20-60% of available roof space can be used as a green roof depending on the characteristics of the buildings such as residential, commercial and institutional. For example, 20% of available roof space must be covered with a green roof for buildings with gross floor area between 2,000 m^2 and 5,000 m^2 (City of Toronto, n.d.).

The bylaw also included green roof design and construction standards which were improved with the help of Green Roof Technical Advisory Group and Ontario Association of Landscape Architects. These standards offer detailed information about the minimum necessities for green roof design, installation and maintenance such as plant selection, irrigation and waterproofing. In addition, Guidelines for Biodiverse Green Roofs were developed to support creation of habitats and enhancement of biodiversity. (Peck, 2019, 27).

4) In order to provide awareness and educate people carried out some practices like building a green roof website and holding technical workshops. Also, the City Council arranged training sessions to give information about the design, construction and benefits of green roofs (City of Toronto, n.d.).

The main reason behind the implementation of Toronto's green roof policy is to fight with climate change especially through the reduction of the GHG emissions. Toronto has achieved the 2020 target through instruments including green roof implementations. According to the 2018 measurements, GHG emissions were 37% lower than the 1990s (City of Toronto, 2018).

In the case of Toronto, the limits of the green roof development have been determined more clearly with legal framework. There has been a significant increase in green roof implementations through the policies and incentives implemented. For example, total of 500,000 m^2 green roofs have been implemented within the scope of the incentive program between 2009 and 2018 (Peck, 2019, 29).

According to the estimations by using the Green Infrastructure Cost-Benefit Matrix of Green Infrastructure Foundation, if 20% of Toronto's roofs were intensive and 80% were extensive, 220 million liters of stormwater would be absorbed, 225 tons of carbon would be sequestered annually. Similarly, it would reduce electricity use by annual 3.2 million kWh for buildings and annual 1.6 million kWh for surrounding buildings because of the mitigation in the urban heat island effect (Peck, 2019, 29).

Toronto has developed the green roof strategy with a commitment at international level. However, adopted instruments are generally responsibilities of the city council. While Toronto City Council has developed green roof policies, it adopted a participatory approach by taking the support of universities, NGOs and the public. Thanks to NGOs like Green Roofs for Healthy Cities, not only people have been informed, but also suppliers have become more reliable about the green roof. In addition, implemented incentives and policies have increased the green roof installation. Finally, setting a legal framework with the Green Roof Bylaw has significantly increased the number of green roofs on the urban scale. It has also contributed to the reduction of emissions, which is the major goal.

4.2 Neighborhood Scale Examples

4.2.1 St. Kjeld's Neighbourhood, Copenhagen

After the UN Climate Change Conference COP15, Denmark specified new strategies to fight the adverse impacts of climate change. Because of climate change, more extreme rainfall events are expected in the future (City of Copenhagen, 2018, p. 11).

Even Copenhagen has been facing extreme rain events in the 2013 and 2014 summers. Sewer systems cannot handle the large volumes of stormwater. This heavy rain can lead to overflowing and damage both urban spaces and the public (City of Copenhagen, 2013, 7)

The City of Copenhagen aimed at enhancing green solutions against the destructive effects of heavy rains at neighbourhood level instead of enlarging the sewage system, because it was an expensive solution and it had not any further benefits (City of Copenhagen, 2016, 7). As a result, the City promoted green and blue solutions including green roofs that are easier, cheaper, and more flexible than traditional solutions (City of Copenhagen, 2016).

During this period, the City of Copenhagen started to focus on green roof technology and identified green roof as an urban design strategy in its climate plan. Therefore, green roof has been integrated into different plans and programs such as Strategy for Biodiversity and Guidelines for Sustainability. In this context, St. Kjeld's Neighbourhood in Copenhagen has been made resilient to climate change (City of Copenhagen, 2018, 11).

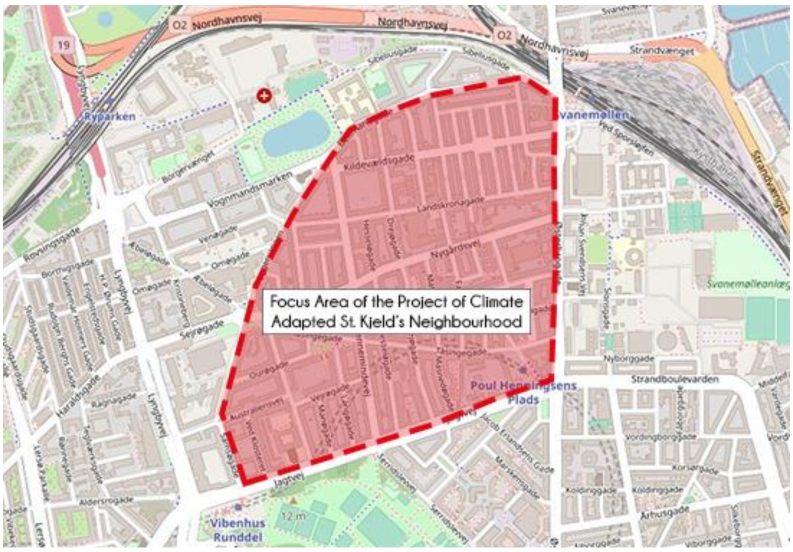

Figure 4.20 St. Kjeld's Neighbourhood

(Personal Drawing on Copenhagen City's Map)

The district encountered several flooding problems especially in winter because the capacity of the sewage system was not enough for the excessive amount of stormwater. This problem originated from the excessive amount of impervious surfaces, and scarcity of green spaces and vegetation (City of Copenhagen, 2016).

One of the most important projects related to green roofs is a rooftop farm in the heart of the climate-adapted St. Kjeld's Neighbourhood. The roof was implemented on a 600 m^2 roof area of the old car-auction house. ØsterGro is a rooftop farm (Figure 4.21) in Copenhagen which promotes the community-supported agriculture (CSA) produce with the help of farms and sell to the 40 members who pay for harvest (Østergro, n.d.). 90 tons of soil were used in raised beds in order to turning the traditional roof into the space of urban agriculture. Moreover, organic vegetables, fruits, herbs and edible flowers, a henhouse, greenhouse and three bee-hives can be found on the rooftop (Figure 4.22). The rooftop farm has been produced vegetables, eggs and honey since 2014 (Klimakvarter, n.d.).

During the growing season of vegetation various workshops, tours, classes, and dinners can be organized. Thus, habitants become closer to organic food production (Klimakvarter, n.d.).

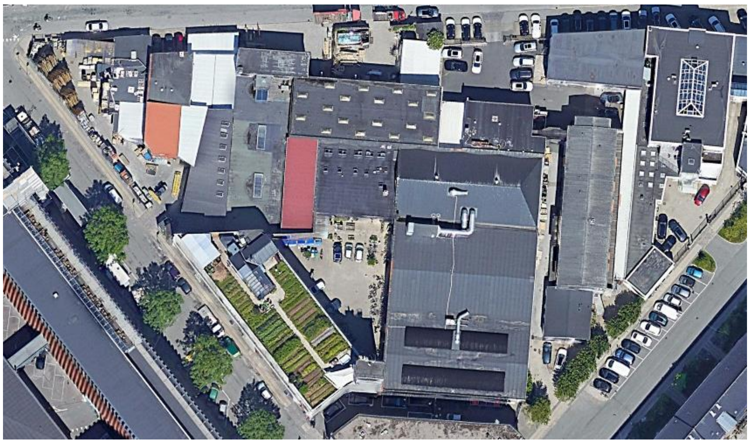

Figure 4.21 Aerial view of ØsterGro Rooftop Farming
(Google Earth, 2020) [Accessed: 15.05.2021]

Figure 4.22 ØsterGro Rooftop Farming
(https://www.kobenhavnergron.dk/place/ostergro/?lang=en) [Accessed: 28.12.2020]

Another public green roof, which covers about 7,000 m^2, was installed on the Danish State Archives building. The achieve building is connected to the Tivoli Congress Center with the landscape bridge because these buildings are adjoining. More than 40 plant species such as perennials, shrubs and tulips were used on the roof so as to create a rich diversity of species. According to the estimations, the roof garden retains almost 60-70% of the stormwater in the area annually. Hence, the roof has an important role in the retention of stormwater besides offering a recreational place to people. Therefore, the green roof includes footpath, cycle route and sitting benches to support socialization of people.

In addition to Østergro rooftop farming and roof garden on Danish State Archives (Figure 4.23 and Figure 4.24), there are variety of green roof installation as part of the project of Climate Resilient Neighbourhood, St. Kjeld's Neighbourhood. For instance, green roofs were implemented on the roof of many bus stops (Figure 4.26) and open-sided huts (Figure 4.25) located on the courtyards (City of Copenhagen, 2018).

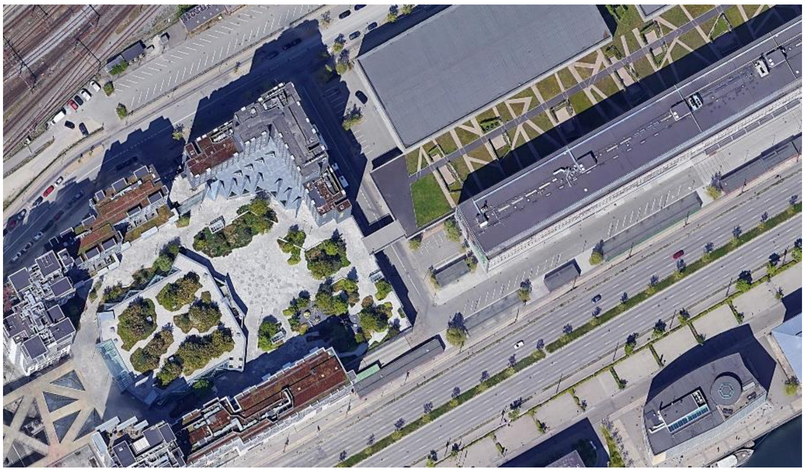

Figure 4.23 Aerial view of green roof on Danish State Archives

(Google Earth, 2018) [Accessed: 15.05.2021]

Figure 4.24 Green roof on Danish State Archives

(http://wsud-denmark.com/copenhagen-green-roof-the-danish-state-archives/home-page/34758) [Accessed: 28.12.2020]

Figure 4.25 Green Roof on open-sided huts

(https://www.kk.dk/nyheder/nu-indvies-fremtidens-gaardhave-i-askoegade) [Accessed: 28.12.2020]

Figure 4.26 Green Roof on bus stop

(City of Copenhagen, 2018) [Accessed: 28.12.2020]

Examples of green roofs mentioned above are just some part of the project of Climate Resilient Neighbourhood. As other components of the project, other green infrastructure instruments such as green corridors, courtyards, and urban gardens were also carried out in the neighborhood to achieve the management of stormwater. Both financial support and information have been provided by the Integrated Urban Renewal Office located in St. Kjelds to local people who want to do their own project. For example, At Bryggervangen, people transformed an asphalted area into a luxuriant urban garden with 30 planting beds (City of Copenhagen, 2016, 23). Thus, local community has been given the chance to adapt their own neighborhoods to climate change.

City of Copenhagen has integrated the green roofs into new local plans by mandating to install green roof in all new buildings with roof slopes up to 30 degrees. Within this scope, City of Copenhagen has implemented green roof on a number of public, residential and commercial buildings. The most of the green roof projects in Copenhagen have been conducted by the City of Copenhagen although the suppliers of the systems are generally provided by private sectors (City of Copenhagen, 2018).

4.2.2 South Bank & Waterloo Neighbourhood, London

Neighbourhood planning is a process that is improved by the community and promoted by the council to provide local people with taking part in their neighbourhood planning. The plan that should encourage sustainable development consists of policies for further development of the neighbourhood. For the two districts of London, namely South Bank and Waterloo (SoWN), a development plan has been prepared with the cooperation of experts, volunteers, and local stakeholders to achieve sustainable developments. The plan that was made under the Localism Act and compatible with the local development plans and policies of City of London offers residents to work together to ameliorate their habitats. (Lambeth Council, 2018, 12).

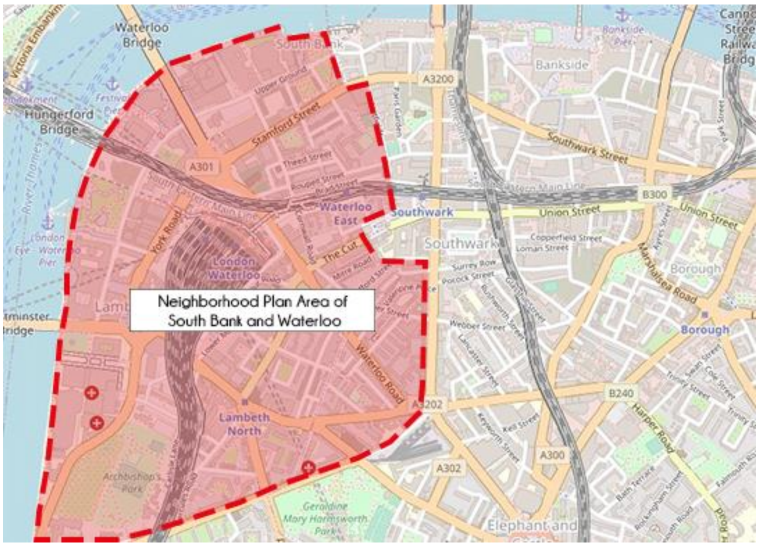

Figure 4.27 South Bank & Waterloo Neighbourhood
(Personal Drawing on London City's Map)

The plan includes policies that were concerned with green roof under the section of 'Green Infrastructure, Open Space & Air Quality'. Main objective of these policies is to ameliorate the health and well-being of the community by minimizing the adverse environmental effects such as the risk of flood, poor connection of open green spaces, and air and noise pollution. The guidelines specified in the plan have created a framework for green roof implementations in the neighborhood (Lambeth Council, 2018,24). The plan states that "*roofs which provide a number of simultaneous benefits, including particularly new open space for the enjoyment of residents are to be supported before other forms of climate change mitigating approaches*" (Lambeth Council, 2018, 26). For this reason, flat roofs should be preferred if possible so that people can occupy the roof garden. Extensive or intensive green roofs have been implemented on the roofs of many public buildings such as of St Thomas's Hospital (Figure 4.28) and Johanna Primary School (Figure 4.26) (London Assembly, n.d.).

Figure 4.28 Green roof on Johanna Primary School

(https://www.oasisacademyjohanna.org/academy-life/pupil-committees) [Accessed 30.04.2021]

Figure 4.29 Green roof on St Thomas's Hospital

(https://livingroofs.org/wp-content/uploads/2019/04/LONDON-LIVING-ROOFS-WALLS-REPORT-2019.pdf) [Accessed 30.04.2021]

One of the most important roof gardens in the South Bank Waterloo district is the roof garden on top of London's Southbank Centre (Figure 4.30). The design and construction of the roof garden was completed with the help of designers, landscape architects and local communities. Also, an important point about the project is that a group of vulnerable people such as drug and alcohol addicts, homeless or mentally disabled individuals took part in this project (Jane, 2011). People can visit the roof garden free and relax among fruit trees, wildflowers and allotment gardens by enjoying the view of London (Figure 4.31). Furthermore, a central café is located on the roof garden to meet the needs of visitors. The roof garden includes vegetable plots, herb garden and lawn area (Figure 4.32). In addition to these, 90 kind of wildflowers were planted on the garden to attract wildlife (Davis Landscape Architecture, 2011).

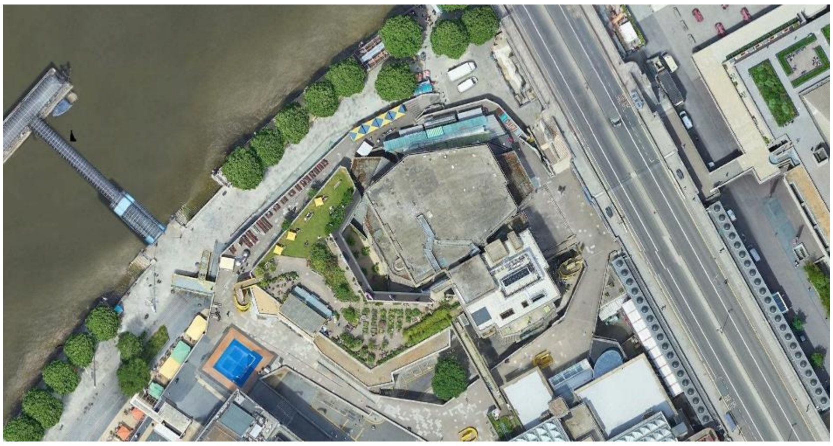

Figure 4.30 Aerial view of green roof on Southbank Centre
(Google Earth, 2018) [Accessed: 30.05.2020]

Figure 4.31 Green roof on Southbank Centre
(https://www.archdaily.com/tag/southbank-centre) [Accessed 30.04.2021]

Figure 4.32 Recreational Spaces of Green Roof on Southbank Centre
(https://davisla.wordpress.com/2011/05/04/roof-garden-created-for-southbank-centres-festival-of-britains-60th-anniversary-celebrations/) [Accessed 30.04.2021]

South Bank & Waterloo Neighbourhood Plan was designed with the principle of including people in the planning process. The issues that local people want to include in the plan were decided with open consultation. Thus, residents could make a decision about their own neighborhood. The item of The Green Infrastructure, Open Space & Air Quality in the plan states that green spaces lose their function due to the intensification of land use. Therefore, it is necessary to focus on green infrastructure, especially green roofs should be implemented on both new and existing buildings.

It is also stated that buildings with flat roofs should be built as much as possible to install intensive green roof. On the other hand, existing buildings should be retrofitted to implement extensive green roof. The plan specified that green roofs provide a number of features such as improving neighborhood's biodiversity, reducing CO2, improving air quality, mitigating flood risk and providing amenity space (Lambeth Council, 2018, 24).

The policies in the South Bank & Waterloo Neighbourhood Plan correspond to local, regional and national plans and documents. Although this plan creates a general framework for the green roof, it does not have any enforcement feature. There was no significant increase in the number of green roofs in the city in line with this plan. However, it is a remarkable example as it provides public participation in process of plan and policy preparation. Thus, the main actor in this case is generally different working groups of public.

4.3 Inferences Gathered from the Examples of Green Roof Implementations at City and Neighborhood Scales

The examples examined in this chapter have been implemented throughout different instruments such as policies, plans, programs, subsidies and regulations. In all the examples analyzed, with the help of the tools mentioned, the green roof practices were realized for their multifunctional benefits.

As far as the city scale examples are concerned, both the City of Barcelona and the City of Toronto adopted holistic approaches which combine different perspectives rather than aiming at a single purpose. Both of them try to discuss social, ecological and economic dynamics in different ways. As described in Sections 4.1.1 and 4.1.2, these approaches aimed at contributing to climate change mitigation and adaptation with green roof implementations.

Taking place in international programs or networks accelerated both cities' involvement in green infrastructure. With Barcelona City Council's commitment to COP21, both quality and quantity of green spaces increased, and green roof implementations were accelerated (Ajuntament de Barcelona, 2018a, 82). Although the green roof is not part of legislation in Barcelona, it takes place in different plans and programs, which are Barcelona Green Infrastructure and Biodiversity, Promoting Living Terraces and Green Roofs in Barcelona, Programme to Promote the City's Urban Green Infrastructure, Plan and Programme to Promote Solar Power Generation in Barcelona.

Toronto is one of C40 Cities, which developed climate action strategies to provide a sustainable future. Therefore, the green roof has been used as a tool to achieve the climate strategies. In addition to green roof implementations with policies and plans, green roof bylaw, which describes the standards of green roof legally, has been put into force in Toronto. Moreover, Toronto City Council has provided subsidy for the implementation of the green roof and organized trainings to raise awareness. Considering all these efforts, it can be said that Toronto is one of the cities that has a comprehensive framework for green roof implementations.

With regards to the green roof implementations at neighborhood scale, like in the city-scale examples, green roof implementations are part of a plan, policy, or project. Green roof implementations in St. Kjeld's Neighbourhood are parts of the project named Climate Resilient Neighbourhood in Copenhagen. Similarly, green roof implementations in South Bank & Waterloo Neighbourhood in London have been realized within the scope of the neighborhood plan.

The following issues can be considered as important inferences from the analysis of city and neighborhood-scale green roof practices:

- Considering green roofs as part of larger green infrastructure network and adoption of green roof practices for their ecosystem services
- Inclusion of green roof practices within a larger urban green infrastructure framework (such as policies, plans, programs or regulations with clear objectives)
- Awareness raising of general public about the green roof by means of introductory guidelines, manuals and even competitions
- Training programs for staff to provide an accurate understanding of the green roof
- Funding or incentive mechanisms to encourage green roof implementations
- Carrying out scientific researches related to the plants for vegetation layer and different kind of materials for substrate layer adapted to different climatic conditions.

CHAPTER 5

GREEN ROOF IMPLEMENTATIONS IN TURKEY

"Yeşili görmeyen gözler renk zevkinden mahrumdur."

Mustafa Kemal Atatürk

The Mediterranean Basin, where Turkey locates, is one of the most vulnerable regions of the world in terms of the global climate change. It is observed that precipitation has decreased by 20% in the last 25 years in the entire Mediterranean Basin. It is estimated that the global warming will be 1ºC in 2025 and in such a case, it is estimated that the temperature increase in the Mediterranean Basin may reach 2˚C after 20-50 years. It is observed that Turkey will be significantly affected by adverse effects of climate change such as the decrease in water resources, forest fires, drought and desertification, ecological deterioration, productivity loss in agricultural products (WWF Türkiye, 2010). For climate change adaptation and mitigation, strong green infrastructure systems in cities can play important roles. In this chapter, the development of the green roof, which is one of the elements in the green infrastructure system, in Turkey will be elaborated.

The green roof implementations in Turkey have started in the mid-1990s. Kaymak (2014, 67) remarks that the first important green roof implementation in Turkey was on the houses of Ankara Mesa Güneş Sitesi in 1978. These are terrace type houses where the roof of one house is the garden of another house. Also, intensive roof gardens with about 30 cm depth with sitting areas and shrubs were implemented above the garages (Figure 5.1) (Kaymak, 2014, 67). Figure 5.2 shows the aerial view of green roofs in Mesa Güneş Sitesi.

Figure 5.1 Green Roofs in Mesa Güneş Sitesi

(Personal Archive)

Figure 5.2 Aerial view of green roofs in Mesa Güneş Sitesi

(Google Earth, 2021)

Some other examples of green roof implementations are on hotel buildings (Köylü, 1997). An example is the Polat Renaissance Hotel which has an extensive type of roof garden with low shrubs and grass (Figure 5.3). Another one is the Ceylan Intercontinental Hotel that is covered with annual flowers and grass implemented for aesthetic purposes (Figure 5.4). Having checked them through satellite images, these roof gardens seem to no longer exist.

Figure 5.3 Green roof on Ceylan International Hotel
(Köylü, 1997)

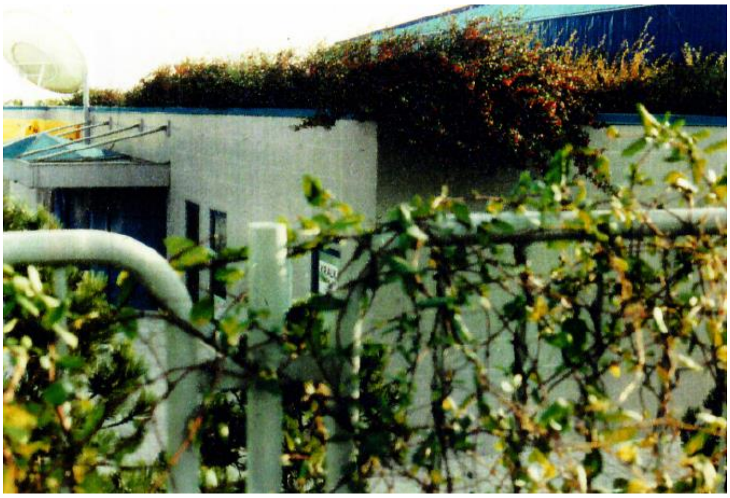

Figure 5.4 Green roof on Polat Renaissance Hotel
(Köylü, 1997)

Green roofs are generally practiced for two main reasons in Turkey. First is to obtain commercial advantages, and second, to be awarded with environmental certification systems such as LEED and BREAM (Kaymak, 2014, 69; Aras, 2019, 494). A common approach in Turkey is implementing green roofs on commercial buildings, particularly on shopping malls. Since green roof and its benefits are not widely known in Turkey, it is mostly implemented to contribute to the advertisement of the structure, and give an aesthetic appearance to the structure (Aras, 2019, 493). In other words, while the aim of green roof examples around the world is generally to contribute the sustainable development by compensating the increasing concrete areas, the aim of green roof examples in Turkey is to create spaces attracting visitors to the buildings.

Vijayaraghavan (2016, 740) underlines *“the knowledge gap that prevail in green roof technology and the need for local research to install green roofs in developing and under-developed countries”.* In Turkey, there are limited studies about the resistant plant species to be grown on roofs for different climatic conditions.

5.1 Some Green Roof Cases from Turkey

This chapter examines the practices of green roof implementation from Turkey. Most of them are individual and building scale examples, which are not part of a neighborhood or urban scale policy.

Eşki states that (2014, 31) the term “roof garden” turned into the term “green roof” over time in the face of environmental concerns. I.e. it has become a component of urban ecology in the last 20 year. Although the term evolved from being an aesthetic element into an environmental element over the years, practices in Turkey have not followed this tendency. Many practices in Turkey are observed on commercial and public buildings with the aim of creating a visual impression, getting environmental certificates such as LEED and BREEAM or providing commercial benefits (Aras, 2019, 494).

There are many worldwide companies that provide green roof systems with all steps of installation. Although these companies offer different options for green roof layers, they mostly provide the vegetation and substrate layers in the climatic conditions of their own country. However, Oberndorfer et al (2007, 826) note that native species are better choices for green roofs, because they are already adapted to local climate. Furthermore, Shafique et al (2018, 762) state that the best substrate suitable for the local conditions should be chosen for the green roof. Therefore, the climatic conditions of Turkey have been ignored in most of the examples mentioned below because green roof systems were supplied by foreign companies.

The green roof of the Meydan Shopping Mall (Figure 5.5 and 5.6) in Istanbul, covers 30,000 m^2 of the total roof area of 55,000 m^2. A 1,000 m^2 section of the roof area can be visited on foot (Şenol, 2009, 79). Both extensive and intensive green roof was implemented depending on the slope of the roof. Generally, meadow plants were used. Besides, shrubs and brushes were also planted where the growing medium was deeper. While choosing plants, the climate of Istanbul, local materials, and native plants were not taken into consideration. The photo seen in Figure 5.7 was taken in August 2021 at Meydan Shopping Mall. As seen in the photo, the plants on the green roofs started to dry.

Figure 5.5 Aerial view of Meydan Shopping Mall
(Google Earth, 2021)

Figure 5.6 Top view of Green roof on Meydan Shopping Mall

(http://www.arkiv.com.tr/proje/m1-meydan-alisveris-merkezi/2010) [Accessed: 24.10.2020]

Figure 5.7 Green roof on Meydan Shopping Mall

(Personal Archive)

Likewise, Zorlu Center (Figure 5.8) also has both extensive and intensive green roof, which covers a total of 72,000 m^2 area at different levels. All green areas in the project including the green roofs, gardens and interior vegetation consist of 3,750 trees, 60,000 shrubs, and over 500,000 perennial plants (Figure 5.9). Also, 200 plant species were used in the project. The most limited use of the plant species was the extensive green roof that is implemented on the roof of Performing Arts Center, which is about 8,000 m^2 (Figure 5.10). This extensive roof which has 10 cm depth includes different sedum species and rosemary and delosperma which are adaptive to Mediterranean Climate (Braun, 2020). In addition, both wastewater and stormwater are stored and filtered in order to meet the water needs of the plants. Therefore, while the green roof at Zorlu Center was implemented, we can say that local conditions were taken into account, albeit partially. Moreover, the use of sustainable solutions such as reuse of wastewater and stormwater harvesting also shows that there is an environmental concern.

Figure 5.8 Aerial view of Zorlu Center
(Google Earth, 2020)

Figure 5.9 Different layers of green roof on Zorlu Center
(https://www.karaoglu.com.tr/en/references/zorlu-center/) [Accessed: 01.08.2021]

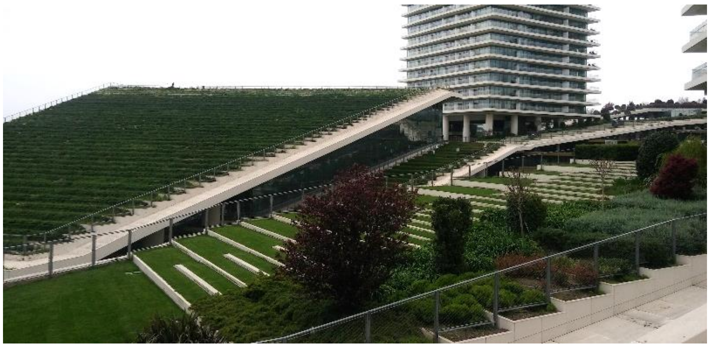

Figure 5.10 Extensive Green Roof on Performing Arts Center
(Personal Archive)

Both examples were built for recreational concerns, not with an ecological perspective. Thus, landscaping was given great importance and these areas are partially open to visitors. The adaptability of vegetation, substrate and other layers to the climatic conditions of Istanbul is not known exactly. As discussed in Chapter 3.3.1, the use of local materials in green roof layers, especially vegetation and substrate, increases the performance of the green roof as well as decreasing the cost of it. For this reason, further research should be carried out for the selection of materials and plants that is adaptive to different climatic conditions in the Turkish cities for green roof implementation process. Thus, the success rate of green roofs implemented in Turkey could be increased.

In addition to the lack of local studies, the incorrect choice of vegetation and substrate materials negatively affects the sustainability of the green roof. For example, the roof of Turkcell R&D building (Figure 5.11) in Gebze, Kocaeli, was designed as a green roof which was completely covered with grass (Yeşil Bina Dergisi, 2015). However, Shafique et al (2018, 761) state that the selection of plants for green roof depends on geograpthic location, humidity, sun exposure and precipitation amount. These factors are important for the quality and durability of the green roof. Covering the green roof completely with grass, which is a hydrophilic plant, contradicts the principles of sustainability. Of course, the benefits it provides cannot be ignored, but it could have been implemented with a plant that needs less water, such as sedums and succulents.

Figure 5.11 Turkcell R&D Building

(http://www.arkiv.com.tr/proje/turkcell-ar-ge-binasi/1497) [Accessed: 01.08.2021]

The second main purpose in implementing green roofs in Turkey is to obtain environmental certificates, which are LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method). These are both international certificates that aim to evaluate the environmental performance of buildings for sustainable planning and building. LEED is an American green building certification system that was introduced in the early 1990s. It was developed to reduce the usage of resources such as energy, water, ground surface and building materials. Similarly, BREEAM is also a green building certification system, which was launched in the UK in 1990 (Vinnova, 2017). These certification systems are implemented in many countries in USA and Europe.

The criteria of certification systems do not directly include the green roof implementation. However, the green roof is a tool that helps to earn credit to achieve the certification. For example, one of the LEED criteria is “Sustainable Sites”. Green roof is known as a sustainable solution that decreases the urban heat island, absorbs stormwater, and enhances biodiversity (Green Roof Technology, n.d.). Hence, they increase the environmental performance of the building thanks to the benefits it provides to the building (Eren, 2018). With the benefits thay provide, they help increasing the building’s score in the building evaluation process.

There are buildings with green roofs in Turkey that gained these certificates. Examples are mentioned in Chapter 3, as the Piri Reis University and Küçükçekmece City Hall which were awarded with the BREEAM Certification, and the Garanti Bank Technology Campus which obtained the LEED Certification.

In addition to these buildings, Bahriye Üçok Kindergarten (Figure 5.12 and 5.13) is the first pre-school institution that earned the LEED Platinum certification in Turkey. The building, which has a green roof, was completed in 2016. The green roof on the kindergarten conserves biodiversity in the environment by getting integrated with the green space in the garden. Also, the green roof provides thermal insulation, and filtration of rainwater (Kaya and Kaya, 2019).

Figure 5.12 Green roof on Bahriye Üçok Kindergarten
(https://www.mimarizm.com/mimari-projeler/egitim/bahriye-ucok-ekolojik-anaokulu_127971)
[Accessed: 01.08.2021]

Figure 5.13 Green roof on Bahriye Üçok Kindergarten with different perspectives
(http://www.dilekci.com/tr/portfolio-item/durmus-dilekci-eco-kindergarten-waf-2017-finalist/)
[Accessed: 01.08.2021]

Another example is the Kuzu Effect building (Figure 5.14 and Figure 5.15), which is the first LEED Gold certified mixed use project in Ankara. 54% of the roof of the building was designed and implemented as a green roof. The plants used in the green roof and green areas in the project have been selected as drought-resistant. 54% less water is consumed in the green roof and garden of the building (Çakır, 2019).

Figure 5.14 Kuzu Effect Mixed Used Project

(https://www.ecobuild.com.tr/post/2019/12/04/kuzu-effect-projesi-ecobuild-c4-b0le-leed-gold-hedefine-ula-c5-9ft-c4-b1) [Accessed: 01.08.2021]

Figure 5.15 Top View of Green Roof on Kuzu Effect

(https://www.ecobuild.com.tr/post/2019/12/04/kuzu-effect-projesi-ecobuild-c4-b0le-leed-gold-hedefine-ula-c5-9ft-c4-b1) [Accessed: 01.08.2021]

The concept of "green roof over the underground carpark", is partially implemented in Turkey. In the Kelebek Sitesi Housing Project (Figure 5.16), which was built in Tuzla, a green roof was built on a total of 600 m^2 above the parking lot. Green roof layers applied in the project are filter layer, drainage layer and 20-25 cm substrate layer (Yeşil Bina Dergisi , 2014).

Figure 5.16 Kelebek Sitesi Housing Project
(Yeşil Bina Dergisi, 2014)

Another example is TOBB ETU Hospital (Figure 5.17) in Ankara. The garden, which was designed as a courtyard on the ground floor of the hospital, can be considered as a green roof implementation. The green roof, which is located over the cardiology department, covers an area of approximately 2000 m^2. Indeed, the ground level of the building is also the roof level of the cardiology department (Ekoyapı Dergisi, 2014). Semih Baydar (2021), the business director of the hospital, states that the hospital staff use the green roof to relax and socialize with each other. There are different shrubs and tree species such as magnolia, sumac tree, Tibet pine, pomegranate tree, and a lot of colorful roses on the roof. Viewing green areas and nature provides people with positive health effects such as lowering blood pressure and reducing stress (Ulrich and Simmons, 1986 cited in Getter and Rowe, 2006). Hence, viewing the green roof from the hospital can contribute to human health.

Figure 5.17 TOBB ETÜ Hospital
(Personal Archieve)

5.2 Procedures for Green Roof Implementations

Regulations about the green roof in Turkey have been developed for the last five years. Article 40/14 of the Zoning Regulation for Planned Areas[1] (03 July 2017) mentions that *"Roof gardens can be arranged on terrace roofs*"[2]. This regulation includes the construction conditions and qualities of green roofs. With this article, which is not obligatory, the green roof concept entered into the legislation in Turkey. Article 44/21 of the Istanbul Development Regulation[3] (20 May 2018) of the Istanbul Metropolitan Municipality Istanbulis as follows:

"Green roof systems are mandatory to be implemenedt on buildings with a total construction area of more than 60,000 m², including public buildings, to improve the urban ecology, reduce the effect of climatic change, reduce floods by filtering stormwater, prevent the destruction of green areas by constructions, create a natural environment, and provide heat and noise insulation on roofs."

Moreover, Istanbul Metropolitan Municipality organized a workshop named "The Legislation Workshop on the Roof Implementations of Istanbul Development Regulation[4]" in February, 2020. Ramazan Gülten, Urban Development Director of the Istanbul Metropolitan Municipality, stated in the workshop that Istanbul Metropolitan Municipality would try to implement the green roof regulation, which allowed agricultural activity on roofs (Yeniçağ Gazetesi, 2020). If the green roof regulation came into effect, it could be a milestone for the development of green roofs in Turkey.

Meanwhile, the Mayor of İzmir Metropolitan Municipality, Tunç Soyer, says that (Cumhuriyet Gazetesi, 2021) İzmir Metropolitan Municipality aims to increase the quality of life in the city with regulations such as rainwater harvesting and green

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[1] Planlı Alanlar İmar Yönetmeliği
[2] "Teras çatılarda çatı bahçesi olarak düzenleme yapılabilir."
[3] Istanbul İmar Yönetmeliği
[4] Istanbul İmar Yönetmeliği Çatı Uygulamaları Mevzuat Çalıştayı

roofs (İzmir Metropolitan Municipality, https://www.izmir.bel.tr ,2021).İzmir Metropolitan Municipality enacted the İzmir Development Regulation[5], which was published in the Official Gazette on the 3 June 2021. The article 43/21 of the Regulation is as follows:

"Green roof systems are mandatory to be implemented on buildings with a total construction area of more than 60,000 m², including public buildings, to improve the urban ecology, reduce the effect of climatic change, reduce floods by filtering stormwater, prevent the destruction of green areas of constructions, create a natural environment, and provide heat and noise insulation on roofs."

It is the same with the Article 44/21 of the Istanbul Development Regulation. These regulations define the green roof as follows: *"green roofs, which can be greened with grass, flowers, and small plants, improve the energy performance of the building, increase air quality and ameliorate urban ecology, bring innovative solutions to the problems created by stormwater runoff."*

These articles can be considered as a step to enhance the green roof practices in Turkey. However, Karaca (2020, 416) states that since the size of the green roof specified in the regulation is too high for a single construction, the implementations of green roofs have not been very effective. The 60,000 m^2 construction area should be modified with small and medium-sized projects with less amount of construction area. Also, clarifying definitions in the regulation such as the height of the building, the floor area of the building will contribute to the efficient use of green roof systems (Karaca, 2020, 416).

Before the regulation was implemented, İzmir Metropolitan Municipality installed a green roof on the Üçkuyular Bus Terminal (Figure 5.18) in 2018 to develop green infrastructure strategies (İzmir Metropolitan Municipality, 2018).

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[5] İzmir İmar Yönetmeliği

Figure 5.18 Green Roof on Üçkuyular Terminal

(http://kentyasam.com/2021/08/02/izmirde-buyuk-yapilarda-yesil-cati-uygulamasi/) [Accessed: 11.08.2021]

In addition to the Üçkuyular Bus Terminal, “the green bus stop” project was implemented at the Konak Bahribaba Transfer Center (Figure 5.19). If it is appreciated by inhabitants, it will be implemented Halkapınar Transfer Center (İzmir Metropolitan Municipality, 2020).

Figure 5.19 Green Roof on a Bus Stop

(https://www.izmir.bel.tr/tr/Haberler/izmir-in-ilk-doga-dostu-otobus-duragi/44465/156) [Accessed: 11.08.2021]

5.3 Concluding Remarks for Green Roof Implementetions in Turkey

This chapter has examined the green roof implementations and policies in Turkey. The green roof systems which are produced by foreign companies according to their climatic conditions are directly transferred, imported, and installed in green roof practices in Turkey. These products, which are imported expensive, do not adapt to the local climate conditions (Kaymak, 2014, p. 69). Thus, the green roofs cannot show the expected performance. For this reason, further studies should be done about green roofs that can adapt to regional and local climatic conditions (Aras, 2017, 286).

In addition, it is necessary to use different plants and substrate materials paying attention to the climatic conditions of different regions. The green roof provides different benefits in different climatic conditions. Same plants meeting certain purposes in a region may not meet the same purposes in another region. For example, in a study conducted in the Aegean region, the energy saving provided by green roofs was calculated. It was assumed that some plant species adapted to the Aegean region were used in the pilot region (Çelik et al, 2010). Green roof was implemented on the roof of the building of Green Roof Research Station of the Landscape Architecture Department, Istanbul University to analyze the thermal properties of green roof within Istanbul's climatic conditions. It has been observed that the green roof prepared with respect to the Mediterranean climate conditions reduces the extreme summer temperatures by 27% (Ekşi and Uzun, 2013, 626). As result, the same plant should not be applied to every region of Turkey and the same results should not be expected.

There are examples of green roof implementations by different public and private organizations in Turkey. However, policies for green roof developed by public administrations in Turkey are limited to the Istanbul Building Regulation and Izmir Building Regulation. Istanbul Development Regulation has obliged green roof implementations for buildings with a total construction area of more than 60,000 m² in 2018, and İzmir Development Regulation has also obliged it in 2021. Apart from this, there are no laws and regulations that directly address the green roof.

It can be said that the green roof started to attract the attention of local governments in Turkey particularly in the last couple of years. Two important metropolitan municipalities, namely Istanbul and Izmir, incorporated green roof policies into their development regulations. With increasing national and international practices and research on urban green infrastructure in general, and green roofs in particular, it may be expected that green roof implementation will be an important agenda for Turkey in near future. A recent example for such studies is *"Belediyeler için Yeşil Altyapı Rehberi"* (The Green Infrastructure Guide for Municipalities) published by the Institute of Urban Studies, which provides guidelines for municipalities. Another example is Şehirlerde *"Yeşil Altyapı ve Doğa Tabanlı Çözümler İyi Uygulama Örnekleri"* (Green Infrastructure and Nature Based Solutions Best Practices in Cities), prepared by the Nature Conservation Center, which includes examples of best practices about green infrastructure.

In addition, there are no incentive mechanisms provided by central and local governments. One of the challenges of the implementation of green roofs is that the initial and maintenance costs are more expensive than the traditional roof (Vijayaraghavan, 2016, 747). For this reason, if any incentive mechanism is provided by the government in this regard, it will contribute to the implementation of green roofs.

Increasing number of green buildings implemented for energy efficiency has also created a positive result in terms of green roofs. It has been shown that green roofs save energy and water in buildings. It can be considered as a step towards understanding the ecological benefits of green roofs (Aras, 2017, 286).

Awareness should be raised about the benefits of green roofs for the development of policies and the incentive system because there are mostly individual green roof examples in Turkey. The green roof has often been a tool to generate social and aesthetic value, not part of a policy in these examples. In Turkey, it has not yet been understood that green roofs are auxiliary elements in creating the green infrastructure in the city (Aras, 2019, 493). However, the green roof should be a part of the green infrastructure and provide multifunctionality.

5.4 Discussion

The elaboration of world examples in terms of green roof practices led to the following inferences, which can provide an analysis framework for green roof practices in Turkey.

- Considering green roofs as part of larger green infrastructure network and adoption of green roof practices for their ecosystem services
- Inclusion of green roof practices within a larger urban green infrastructure framework (such as policies, plans, programs or regulations with clear objectives)
- Awareness raising of general public about the green roof by means of introductory guidelines, manuals and even competitions
- Training programs for staff to provide an accurate understanding of the green roof
- Funding or incentive mechanisms to encourage green roof implementations
- Carrying out scientific researches related to the plants for vegetation layer and different kind of materials for substrate layer adapted to different climatic conditions.

1. Considering green roofs as part of larger green infrastructure network and adoption of green roof practices for their ecosystem services

The examples in Turkey are mostly individual implementations for energy saving in buildings or for providing commercial advantages. In order to create an effective green infrastructure system, green roofs must be included in the larger green infrastructure network. It is important to move away from individual practices and adopt a holistic approach that refers to the city scale. Through a connected and multi-functional green infrastructure, ecosystem services can be achieved in the cities.

2. Inclusion of green roof practices within a larger urban green infrastructure framework (such as policies, plans, programs or regulations with clear objectives)

There are some attempts by some local governments in Turkey to incorporate green roof implementations into a larger urban green infrastructure framework, but, a widespread approach for entire cities is yet to come. It is important to develop green infrastructure programs at local scale, and incorporate green roof into that framework.

3. Awareness raising of general public about the green roof by means of introductory guidelines, manuals and even competitions

The concept of green roof and its benefits are not widely known. Green roofs are generally implemented for recreation and aesthetic purposes in Turkey, therefore, an awareness raising is needed about its multifunctional benefits. Some introductory manuals and guidelines mentioned in chapter 4 can be prepared. A green roof competition can be organized like in Barcelona.

Another issue that is frequently observed in policies of green roofs abroad is the implementation of green roofs on public buildings. There has been certain progress in this regard in Turkey, too, as in the examples of the Küçükçekmece City Hall, Piri Reis University and some others. Raising awareness is essential for an effective green infrastructure system.

4. Training programs for staff to provide an accurate understanding of the green roof

Training programs not only inform staff (at local or central administrations) about the design and construction processes of green roof implementations but also gain the ability to manage these processes. Training also helps to raise awareness. For this reason, training programs can be organized by municipalities, universities, or nongovernmental organizations in order to evaluate the green roof potential. Such training programs have not yet been started to implement in Turkey.

5. Funding or incentive mechanisms to encourage green roof implementations

As mentioned in Section 3.3.2, it is necessary to provide funding or incentive mechanisms to encourage people for green roof implementations on their buildings, since the initial cost of the green roof is higher than the traditional roof. Although it compensates the initial cost in a few years with the benefits it provides, higher costs at the initial stage might discourage people.

6. Carrying out scientific researches related to the plants for vegetation layer and different kind of materials for substrate layer adapted to different climatic conditions.

In order to develop green roof policies and programs for more effective practices, universities, research centers, central and local administrations should seek answers to such questions as whether endemic species in Turkey can adapt to roof conditions, which plants should be used in different climatic conditions in Turkey, what should be chosen for the substrate materials, how green roof can be incorporated into a wider green infrastructure policy, etc.

CHAPTER 6

CONCLUSION

"*We cannot solve our problems with the same thinking we used when we created them*."

Albert Einstein

This study has elaborated the green roof concept as an element of green infrastructure. The implementations, as portrayed, can be at building, neighborhood or city scales. It has been identified that green roofs can be a very effective method in mitigating the effects of climate change, especially in dense areas through its multiple benefits. In this study, the green roof is not considered as a means to substitute other ecosystems in the city such as forests, urban parks, open and green spaces. Rather than that, it can be a supplementary method to decrease the effects of climate change in cities. Green roof implementations, which are performed as part of a holistic framework such as policy, plan, program or regulation, can be more effective for both the building and the urban environment. Most of the practices in Turkey so far represent building scale examples, not part of such a larger framework. Adoption of a holistic approach that considers the green roof as a component of the green infrastructure can lead to more effective results in providing ecosystem services and combatting climate change.

The thesis has focused on two important points:

1) Green roof implementations can be part of green infrastructure and they can be included within holistic perspectives such as policies, plans, programs and regulation.
2) For more effective outputs the green roof concept should be addressed at larger scales such as neighborhood or city scales.

Problems caused by disturbance of ecosystems such as the inability to absorb stormwater and the excess amount of solar energy have accelerated climate change. Green infrastructure is considered as one of the most effective methods used to combat climate change. It is a holistic approach for sustainable urban planning, since it enhances the benefits provided by nature and procures ecosystem services (Hansen and Pauleit, 2014). The most important characteristics of green infrastructure that distinguishes it from green space are multi-functionality and connectivity. The green infrastructure can be implemented at different scales from building scale to urban scale.

Multi-functionality refers to the environmental, social and economic benefits of the green infrastructure. Furthermore, it can be said that multi-functionality is the most important principle that plays role in the provision of ecosystem services. Meanwhile, connectivity principle needs to be evaluated not only physically but also functionally. It focuses on the spatial distribution and interactions of green infrastructure elements (Hansen and Pauleit, 2014, 520). Connectivity emerges as a result of the interaction of the functions and structures of green infrastructure elements such as water flow and maintenance of biodiversity (Ahern, 2007, 270).

The green roof has been evaluated with regards to these principles as an element of the green infrastructure. Green roof has environmental (stormwater management), social (aesthetic and amenity value) and economic benefits (energy conservation), so it can be assessed under multi-functionality principle. The green roof has also connectivity principle because it can function in connection with the surrounding green spaces. From a functional point of view, the synergy that the green roof creates with different green infrastructure can generate different ecosystem services. Although the green roof is a tool implemented at the building scale, it can also be evaluated at different scales within the framework of a policy, plan, program or regulation.

As elaborated throughout the study, green roof provides multi-functional benefits at different spatial scales, and its physical and functional connectivity with a larger green infrastructure can ensure a stronger system. If the green roof is implemented by considering the principle of integration, more effective results can be obtained in reducing the effects of climate change. Roofs have a great potential to create a habitat as they are unexploited and undisturbed spaces. From the ground level to the balcony level and up to the roof level, different heights and levels can work together as a connected green infrastructure network in cities. A more effective green infrastructure system can be created by ensuring the continuity of various green textures at different levels in cities.

It is important to develop such spaces through the collaboration of different disciplines like architects, landscape architects, ecologists, and urban planners in order to achieve integration. Creation of a nonconventional social and ecological space at the roof level with the collaboration of such disciplines can raise awareness that the green space is not only composed of simply grass.

Identification of plant species and different types of substrate suitable for different climatic regions across Turkey can not only create positive results in terms of green roof development, but also ensure the diversity of green spaces at different levels. Relatedly, the widespread use of grass, a plant that requires excessive use of water, can be reduced, and more sustainable choices can be preferred. Hence, the perception that green spaces should consist of grass can be redefined by introducing different types of plants.

The study has exemplified green roof practices in different countries. Barcelona and Toronto, which display city scale green roof implementations, have developed green roof implementations in line with their global commitments to combat climate change. Barcelona is a dense and crowded city and it does not have enough space for green space implementation at the ground level. The Barcelona City included green roofs in many plans and programs, which are Council Barcelona Green Infrastructure and Biodiversity, Promoting Living Terraces and Green Roofs in Barcelona, Programme to Promote the City’s Urban Green Infrastructure Plan and Programme to Promote Solar Power Generation in Barcelona (Ajuntament de Barcelona, 2018a).

Similar to Barcelona, in Toronto, green roof implementations were started by incorporating them into various plans, such as Environmental Plan, the Official Plan, the Wet Weather Flow Master Plan, Toronto Green Standard and Toronto Clean Air and Climate Change Action Plan (Loder, 2011, 48) Over time, Toronto has made green roofs mandatory with the incentive policies and awareness it has created.

Similar cases can be seen in the examples at the neighborhood scale. Following the development of a plan or project at the upper scale, green roof implementations are developed with regard to tha framework. Green roofs have been implemented in St. Kjeld's Neighbourhood in Copenhagen within a project that aims to generate a climate-adapted neighborhood. Green roofs have been implemented in the South Bank & Waterloo Neighbourhood in London within the scope of the neighborhood development plan.

There are efforts in order to reduce the effects of climate change in the examples of green roof implementations at both city and neighborhood scales. Holistic approaches are generated and awareness is increased with policies and plans. Hence, green roofs which are implemented deliberatively, are an element of green infrastructure.

As far as implementations in Turkey are concerned, most of the practices have been realized to increase commercial attractiveness and provide energy savings at the building scale. Obviously, even at the building scale, green roof implementations provide certain benefits. However, seeing the green roof as an element of green infrastructure can be more effective as elaborated throughout the study.

The research related to the appropriate plants for vegetation layer, local material for the substrate layer, and how green roofs should be adapted to different climatic conditions in Turkey should be enhanced. With more research about such issues, more effective and durable green roof implementations can be realized. Research about countries with similar climatic conditions to Turkey can be examined. Barcelona shows the characteristics of the Mediterranean climate like Turkey, and it can be examined as an example for green roof implementations in the Mediterranean region. Obviously, together with such analysis, any country's specific conditions should be studied carefully as well. In addition, remote sensing technology can be used to determine appropriate roofs (Irga et al, 2017). It is also important to inform the society about the benefits of green roof.

In Turkey, there are some recent regulations that mention the green roof concept, which are, İstanbul Development Regulation and İzmir Development Regulation. While there is no obligation about the green roof in the Zoning Regulation for Planned Areas, it is mandatory over 60,000 m² buildings in İstanbul and İzmir Development Regulations.

Incentive mechanisms can be developed for green roof implementations. One of the reasons why people do not want to install green roof is that green roofs are more expensive than the traditional roof. Therefore, if any incentives are provided by local or central governments, people can overcome the initial cost more easily.

Consequently, the thesis has elaborated the green roof as an element of green infrastructure with regard to the approaches and principles implemented in different cases, and deducted urban policy implications for more effective implementations in Turkey.

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