POLITECNICO DI TORINO

MSc. In Architecture for the Sustainability Design

Master's Thesis

GREEN ROOFS IMPLEMENTATION IN THREE DIFFERENT CITIES: NAIROBI, TURIN AND ISTANBUL

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ABSTRACT

Green roofs are becoming a common phenomenon when it comes to sustainable architecture. The increased urbanization and industrialization of cities has led to the eradication of plenty of urban green spaces on ground which influences pollution and climate change making the cities less breathable. Many countries around the world have mandated the adoption and implementation of green roofs on newly constructed buildings because of the multiple benefits and ecosystem services they provide, in an attempt to reduce the impact of human activities and climate change.

This dissertation talks about the evolution of green roofs, the benefits of green roofs which include mitigating urban heat island effects, reduction of pollution, energy saving, increased biodiversity among others. It also analyses the challenges, the main one being the high cost of construction and maintenance. However, the advantages of green roofs outweigh the cons. This shows the importance of implementation of green roofs in cities around the world.

Moreover, this research focuses on the in depth analysis of green roofs implementation in three different cities across the globe namely, Nairobi, Turin and Istanbul. The analysis and discussions provide a deeper look into the similarities and differences in the urbanization trend and its effects, the social perception of green roofs, the use of green roofs in the cities, climatic conditions, type of construction, architectural conditions and green roof regulations or policies. A specific case study for each city is studied to give a better understanding of the advantages and challenges of constructing a green roof.

Additionally, this research includes innovative trends and recommendations for the implementation and better performance of green roofs.

CONTENTS

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Increase in urbanization in cities around the world has led to the depletion of natural greenery. The concentration of tall buildings and hardscapes in urban cities is way more than green spaces hindering the breathability of the city. The lack of greenery means lack of transpiration and natural canopy which leads to increase in temperatures creating the urban heat island effect (Berndtsson, 2010). It is also noted that nearly 40 percent of energy used worldwide is in relation to construction and maintenance of buildings (Berardi, 2012). Additionally, buildings are responsible for 33 percent of the world's emissions of greenhouse gases (Berardi et al. 2014).

To counter these problems, multiple eco-strategies are being implemented. One of which is the application of green roofs on buildings to make them more sustainable. Green roofs, also known as vegetated roofs, eco roofs or living roofs, are roofs that have vegetation grown on top of the growing medium. This technology was created with the intention of encouraging the growth of different types of vegetation on top of buildings, which would have aesthetic, environmental, and financial advantages. Vegetation, substrate, filter fabric, drainage material, root barrier, and insulation are typical components of green roofs. Each component's function in an engineered green roof system is well defined, and the type of each component varies according on the climatic region (Vijayaraghavan, 2016).

Green roof technology is gaining popularity around the world due the many benefits it provides which include, increase in biodiversity, mitigation of urban heat island, decrease in pollution and reduction in storm water run-off among others (GSA, 2011). However, green roofs come at a high cost of construction and maintenance. Due to this, many people opt out of constructing it. Many countries around the world have started the implementation of green roofs and some also creating mandates for the implementation of vegetated roofs due to the benefits. This shows the increase in interest of establishment of green roofs across the world.

In recent times, research and experiments by many authors are being conducted with the aim of measuring the quantifiable benefits and application of green roofs in different climatic regions around the world. Europe and America is more popular with the concept of green roof technology compared to Africa. A lot more research on green roofs is conducted in the Western countries compared to the developing ones. Therefore, there is a great need for green roof research in developing countries.

The structure of the thesis includes a theoretical framework, references, case studies in three different countries and a conclusion. The framework explains in detail the general information about the history of green roofs, its components, the benefits and constraints. The thesis aims at understanding the similarities and differences of green roof aspects and technology in three different regions around the globe; Nairobi, Turin and Istanbul. The comparison is based on urbanization, social perception, climate, type of construction and government policies for construction of green roofs. In addition, this research provides recommendations and strategies for implementation of green roofs. The outcome proves the gap of implementation and research of green roofs between these three cities.

1.1 Methodology

This thesis is essentially a qualitative research. It includes a theoretical framework in which primary and secondary research methods were used. The study involves case studies of implementation of green roofs in three cities, Nairobi, Turin and Istanbul and their comparisons. The data on the case studies was obtained by extensive research using online and offline materials and semi-structured interviews with the architects and landscape architects of the specific case study project in Nairobi and Turin. In addition, the programs used in aiding of site analysis and creation of maps were Google Earth, Open Street Maps, Geoportale Torino while the representational tools used were AutoCad, Adobe Illustrator and Adobe Photoshop.

CHAPTER 2

THEORETICAL FRAMEWORK

2.1 EVOLUTION OF GREEN ROOFS

As much as green roofs and rooftop gardens have become popular in this day and period, they originated thousands of years ago. Even though there exists records of roof gardens from long ago, little physical evidence remains (Osmundson, 1999). In ancient times people constructed vegetated roofs using sod (Figure 1) for insulating purposes and a get away from the stress of the urban environment (Magill, 2011).

The first man made roof gardens are known to be the Ziggurats of Ancient Mesopotamia which were built from 400 BC to 600 BC (Osmundson, 1999). Trees and shrubs were planted on the step like structure which reduced heat levels by shading and evapotranspiration as shown in figure 2 (Alexandri, 2006). The Hanging Gardens of Babylon, one of the Seven Wonders of the World, built around 500 BC, was also one of the most famous ancient green roofs (Figure 3). The vegetated tiered stone constructed structure was built to resemble the mountain landscape where the Queen resided (Osmundson, 1999).

In recent times, during extreme climatic conditions, many people in countries such as Sweden, Finland, Iceland, Denmark, Norway, Greenland, Vinland, and the Faroe Islands tend to cover their rooftops with sod for insulation purposes (Shafique et al. 2018). Present green roofs therefore take their concept from the ancient system. However, due to technological advances, new techniques and proper design, green roofs and rooftop gardens are more efficient and effective.

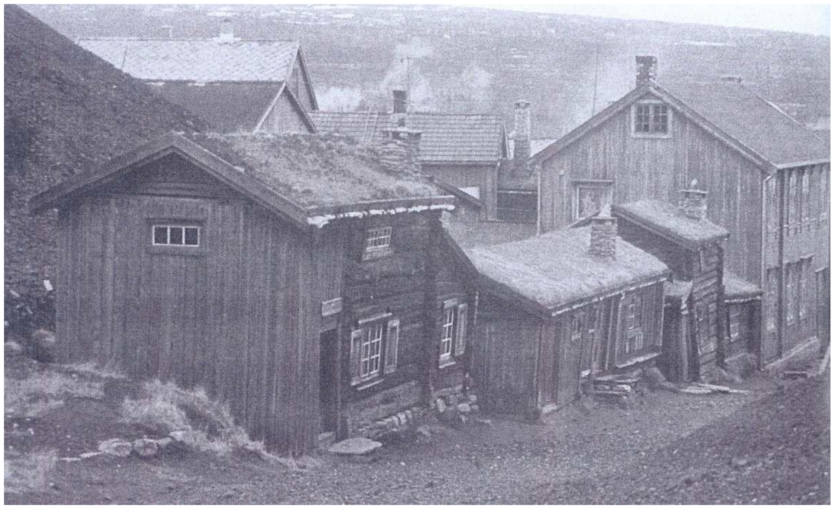


Fig. 1 Miners' houses with turf roofs dating from the 17th to the 19th century in Røros, in Sør-Trøndelag, Scandinavia (Donnelly, 1992)

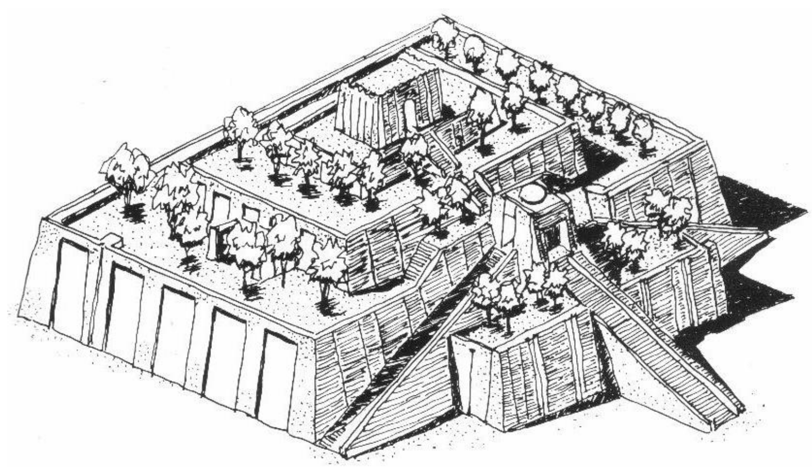


Fig. 2 The ziggurat of Nanna, in today's southern Iraq (Osmundson, 1999)

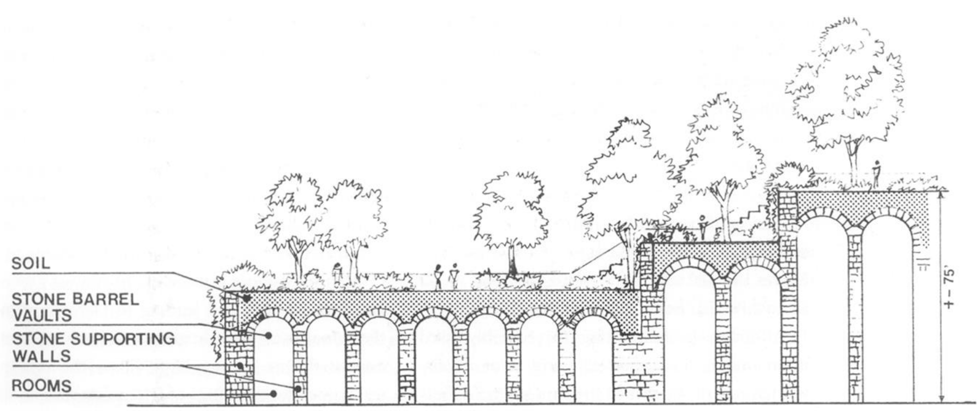


Fig. 3 Section of the Hanging Gardens of Babylon (Osmundson, 1999)

Modern day green roof technologies were initially developed and implemented in Germany in the early 1960’s. Vegetation was installed on roofs to protect the roof structure from the adverse physical effects of solar radiation (Magill, 2011). The green roofs were also used as fire retardant structures (Köhler, 2003). In the 1970’s, significant technical research was conducted on the various components of green roofing technology, including studies on root repelling agents, waterproof membranes, drainage, light-weight growing media, and plants (Magill, 2011) and by the 1980’s, the green roof market became popular in Germany and many green roofs were constructed. Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) published guidelines for constructing green roofs in the German language (Shafique et al. 2018).

In Germany, green roofs were used in more than 10% of the buildings. Most of the research and studies about green roofs was then published in German since many people in Germany began implementing the use of green roofs, therefore there was no readily available information internationally in English (Mentens et al 2006). However, green roofs became popular in Europe and around the world after being initiated by Germany. Recently, green roof coverage has increased by approximately 13.5 million m^2 per year in Germany alone. (Oberndorfer et al 2007).

In 2002, FFL published guidelines for green roof construction in English. (Magill, 2011) and in 2005/2006, guidelines for green roofs were released by Association of Standards and Testing Materials (ASTM) where the detailed construction of a green roof was explained. The most recent guidelines by FLL were published in 2008 for the planning, implementation and upkeep of the green roofs. In 2009, a report explaining the construction and the benefits of green roofs was released by USEPA (Shafique et al. 2018) which shows that there has been more research about the guidelines for green roof construction going on.

Currently, countries such as USA, Canada, Australia, Singapore and Japan are making a concrete effort to install green roofs in the construction of new buildings and renovating old ones in a way to allow green roofs to be added in the near future (Vijayaraghavan, 2016). In Toronto, Canada, it is mandatory for all new building developments with a floor area of ≥ 2000 m^2 to include a vegetated roof on 20-60% of the area (Chen, 2013). Likewise, Tokyo, Japan increased the use of green roofs by mandating all new constructions to install vegetated roofs whereby, private buildings larger than 1000 m^2 and public buildings larger than 250 m^2 are required to have 20% of green roofs or pay a large penalty of 2000 dollars annually (Chen, 2013). Also, green roofs on new buildings in Portland, USA must be implemented on 70% of the areas (Townshend, 2007). Similarly, China, Hong Kong and South Korea encourages the use of green roofs and green practices as a way of attaining the environmental and ecological benefits.

There has been a lot of research on green roofs which has been done through the years. Most of the research originates from the Scandinavian countries in which early research was more focused on highlighting the benefits of green roofs. Nowadays, the research to identify the components for successful implementation of green roofs is being done considering the climatic condition of the region and building characteristics of buildings built in a different country (Vijayaraghavan, 2016).

As cities have developed to have more built environment than greenery, the market for green roofs across the world is increasing mainly for environmental, ecological and social reasons. Green roofs have become vital in urban revitalizaion of cities. Hence, architects these days are incorporating green roofs in their designs widely across the world.

2.2 GREEN ROOFS IN URBAN SCALE

The notion of green roofs being an ecosystem strategy in mitigating climate change has come around due to the effects of urbanization. Population increase has led to the drastic increase in building constructions across the world making cities bigger. The development of the building sector is responsible for the increase in greenhouse gases by 3% between 2000 and 2010 in addition to the increase in energy consumption caused by human activities where the building sector is liable for almost 40% of global energy consumption (Abass et al. 2020).

A sustainable solution for reducing effects of climate change is the implementation of green roofs in urban areas. As building roof surfaces constitute to 20-25% of the urban areas, application of green roofs can help reduce the air and surface temperature reducing the urban heat island effect and moderate air pollution among other benefits (Abass et al. 2020). Many countries including Germany, Korea, Japan, France and USA among others are now having policies on the subject of green roofs on new constructions. In addition, retrofitting green roofs on existing buildings in developed areas is also an option. However, the structural capacity of the building should be considered when implementing a green roof on an existing building to avoid the risk of collapsing.

The concept of green roof in urban areas was brought by the idea of constructing a living roof on a concrete roof using new technology in the World Expo in Paris in 1867. The technology of the model included the use of a waterproofing and drainage system making it the first design of an extensive green roof (Dunnet and Kingsbury, 2008). As development increased in the 20th century, architects such as Le Cobusier and Frank Lloyd Wright began implementing green roofs in their architectural designs. While Le Cobusier used green roofs as a mode of urban space, Frank Lloyd Wrights purpose of implementing green roofs was to integrate his buildings with the surrounding landscapes. Although both architects used green roofs initially, both were not profoundly aware of the impact vegetated roofs would have economically and environmentally in todays times (Kady and Yahya, 2015). Architects today continue to design green roofs not only as a sustainable strategy but also as a new way for people to socialize by making the green roofs accessible to the public.

Green roofs are prominent in urban cities in developed countries such as Germany, Canada, USA, Japan, Singapore, South Korea and Hong Kong as a way of mitigating climate change. All these countries have established policies, guidelines and regulations for the application of green roofs resulting in a success for their implementation. On the other hand, the application of green roofs in African countries and other developing countries are few and have potential to be inspired by the developed countries to formulate policies and guidelines to increase the implementation and therefore the success of vegetated roofs.

2.3 DEFINITION AND CLASSIFICATION OF GREEN ROOFS

A green roof is defined as layer of vegetation with a growing medium constructed on top of an artificial structure like a building, covering it fully or partially. Green roofs are commonly referred to as eco roofs, green roof infrastructure, living roofs, brown rooftop and bio roof (Rahman et al. 2012). Green roofs are structurally engineered with the intention of mitigating the negative effects of urbanization due to its many benefits (Shafique et al. 2018).

Green roofs have been classified under different categories. The following classification has been done according to; 1) Typology by depth, use and maintenance, 2) installation methods and 3) Roof surface inclination.

1. Typology by depth, use and maintenance.

Green roofs in this category have been classified into three types namely; extensive, semi-intensive and intensive. They differ in terms of the kind of vegetation, the composition and depth of the growing substrate, the need for irrigation and the type of drainage layer used for retaining the excess water (GSA, 2011).

1.1. Extensive green roofs.

These roofs are generally made of a thin growing substrate of about 15 to 20cm thick and house plants that do not require maintenance, and can resist high temperatures and strong winds including sedums and mosses among others. The roof is lightweight due to the thickness of the growing medium requiring less structural support (Oberndorfer et al. 2007). The need for irrigation on extensive roofs depends

Fig. 4 Extensive Green roof on 18th street residential building in New York, USA Retrieved from greenroofs.com Oct. 2021

on the climatic condition of the area located in. Green roofs in areas with peak summer or drought conditions may require irrigation during those periods. According to the characteristics of extensive green roofs, retrofitting is easier. The installation takes a short time and the cost of installation is lower compared to the other types of green roofs.

1.2. Semi-intensive green roofs

These roofs require a thicker layer of growth medium of about 12 to 25cm thick. In addition to mosses and sedums used in extensive green roofs, plants used in semi-intensive roofs include flowering plants, herbs, taller grasses and shrubs. Semi-intensive green roofs entail a bit more maintenance since the plants need irrigation, fertilization and pruning. The cost of installation of these roofs is generally higher than extensive green roofs.

Fig. 5 Semi-intensive Green roof on Chicago City hall, Chicago, USA
Retrieved from greenroofs.com Oct. 2021

1.3. Intensive green roofs

These roofs are typically accessible to people which allows architects to freely design for aesthetic and social purposes. Intensive green roofs impact the structural design greatly because of the thickness of the substrate and the kind of vegetation making the roof heavier (FLL, 2002). The substrate thickness ranges from about 15cm up to 1m depending on the type of vegetation grown. The roof can accommodate all kinds of vegetation including trees and large shrubs. Intensive green roofs require the

Fig. 6 Intensive Green roof, Namba Parks, a retail and office complex in Osaka, Japan
Photo by Yuji Kotani, retrieved from guardian.com, Oct. 2021

most maintenance due to the need for regular irrigation, pruning and fertilizing. The cost of these roofs is generally high. However, they are favourable to use in the long run because of the benefits provided such as energy efficiency and storm water management which aid in the mitigation of climate change.

Green roof typologies comparison

Fig. 7 Green Roof Typologies illustration.
By Author

Green roof typologies characteristics

CHARACTERISTIC	EXTENSIVE	SEMI-INTENSIVE	INTENSIVE
THICKNESS	6-20cm	12-25cm	15cm > 1m
WEIGHT	60-150kg/m^2	120-200kg/m^2	180-500kg/m^2
VEGETATION LAYER	sedums, mosses, herbs, succulents and grass	perennials, turf grass, shrubs, flowers, small food crops	perennials, lawn, shrubs, grass, flowers, trees
SUBSTRATE TYPE	lightweight, low organic matter	lightweight to medium, low organic matter	lightweight to heavy, can have higher organic matter, higher water holding capacity
IRRIGATION	little or no	required periodically	required
COST	low	middle	high
MAINTENANCE	low	periodically	regularly

Table 1. Green Roof Typologies characteristics.
Adapted by author from (GSA, 2015 and Oberndorfer et al 2007)

2. Method of installation

Another way of classification is according to the method of installation. Green roofs can be installed using 3 different methods; Mat system, Built-in system and modular system.

2.1. Mat system

This method involves pre-cultivated vegetation blankets. The growing medium, vegetation, drainage layer and root barrier are placed as mats on a rooftop of an existing structure. This system can be used on buildings with low weight capacity and structures with a large roof for easy installation. This kind of system is suitable for extensive green roofs.

2.2. Built-in system

The built in method, also known as the complete system is used in construction of both extensive and intensive green roofs. It is the most common method, however installation takes a longer period of time compared to the other installation methods. This system includes a continuous construction of the vegetated roof directly on the structure. Each component of the green roof is installed as an integral part of the roof which makes it a complete system (Oberndorfer et al. 2007).

2.3. Modular system

This system involves the use of trays with a water storage system, which allows the soil to absorb water through evaporation. The vegetation is planted ex-situ and placed on the roof deck with a waterproofing membrane. The modular system is mainly used for extensive vegetation and can be applied on both flat and sloped roofs. The cost of installation and maintenance is reduced due to the fact that the vegetation is planted offsite in trays that are made of plastic or other recycling materials (Wilkinson et al. 2016).

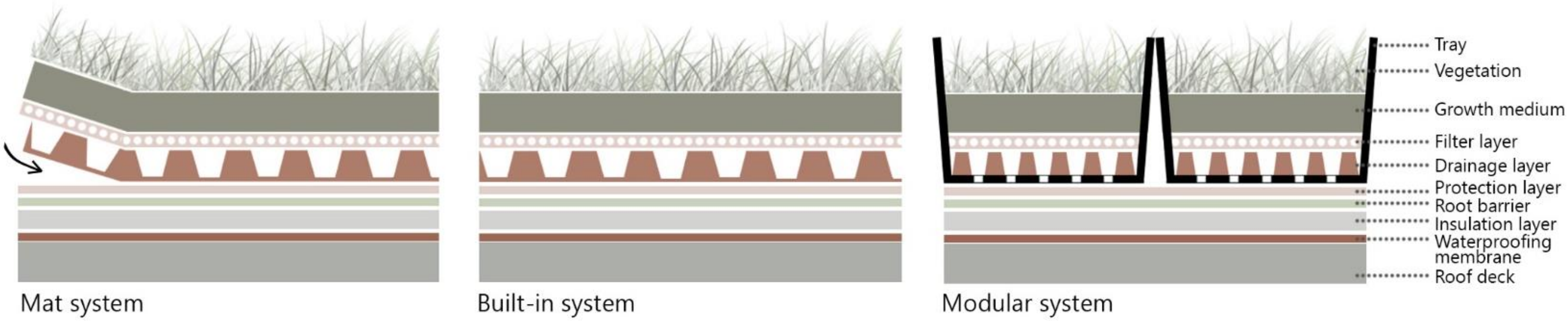


Fig. 8 Green roof installation systems.
Modified by author from (Oberndorfer et al. 2007)

3. Roof surface inclination

Green roofs can also be classified according to the roof surface inclination. Vegetated roofs can be retrofitted or newly constructed according to the architects design. Thanks to the advancement in technology, green covers can be installed in flat and sloped or pitched roofs. Additionally, rooftop vegetation can be installed in other roof shapes and designs including curved and botched roofs.

3.1. Flat roofs

Flat surfaces are mostly used for green roofs since they can accommodate all types of green roofs and do not require a lot of consideration when constructing compared to sloped surfaces. In addition, all types of installation methods are suitable for flat roofs. The maximum angle that is considered for a flat roof is said to be 10^0 (Wilkinson et al. 2016). Green roofs with more inclination would require additional stabilization measures. For flat roofs, a pitch of 1.1^0 is recommended for drainage purposes. Roofs with less than 1.1^0 slope would need a drainage layer with appropriate dimensions to avoid waterlogging in the vegetation layer and to manage with water run-off (FLL, 2002).

3.2. Sloped or pitched roofs

Inclined surfaces are suitable for extensive green roofs. As for intensive green roofs, sloped surfaces are structurally unsuitable. The slope range for a pitched roof is from 10^0 to 50^0. However, as per the commercial brand ZinCo (2021), the maximum pitch is said to be 35^0. To construct a green roof on a sloped surface, the degree of pitch should be considered. The higher the slope, the more likely for the substrate to move and slip especially in heavy rains and increase water run off the roof. Therefore, measures to prevent slipping of the substrate are taken using support brackets. These are attached to the roof substrate and sealed separately (Wilkinson et al. 2016). Other methods to avoid slipping include the use of horizontal straps, laths, battens and grids (Friedman, 2015).

For pitched green roofs, as the slope increases, the water run-off increases, reducing the water retention capacity. This calls for additional integrated irrigation systems for use during dry seasons to prevent erosion and destruction of plants. Accessibility for maintenance for the sloped green roof is usually challenging. Therefore, it should be taken into consideration when designing the eco-roof.

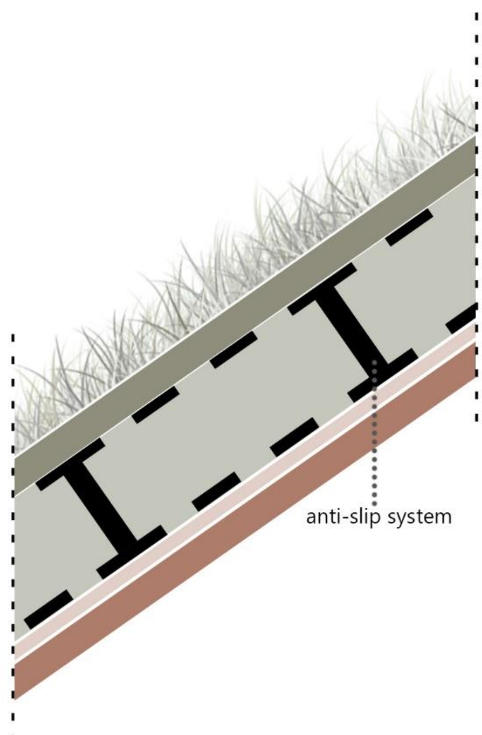


Fig. 9 Sloped roof of 35^0 with anti-slip system.
Adapted by author from (ZinCo, 2021)

2.4 COMPONENTS OF A GREEN ROOF

The components of a green roof vary depending on the location and requirements. A green roof is comprised of a vegetation layer, a substrate layer; which retains water and is the growing medium, a filter fabric, a drainage layer; to release excess water, a protection layer, a root barrier membrane, an insulation layer and a waterproofing membrane. Fig 1. shows a structure of a typical green roof with its components. It is important to select each layer according to the location and climatic condition for long term environmental benefits (Shafique et al. 2018, Vijayaraghavan, 2016).

Fig. 10 Typical components of a green roof. (Vijayaraghavan, 2016).

1. Vegetation

The upper most layer is the most important layer in the development of green roofs which brings life to the green roof system. The success of any green roof is determined by the health of the plants. Different species of plants can be used on the roof top. While selecting the plant type, the geographical location, humidity, rainfall, wind and sun exposure should be considered. Another factor that determines the kind of plant species used is the depth of the growth substrate (Shafique et al. 2018). Many authors worked to identify plant species based on soil depth. The following plant species can be used in relation to the depth of soil (Mobasheri 2014).

- Sedum mosses and lichens for 0-5 cm soil depth.
- Short wildflower meadows, long-growing, drought-tolerance, perennials, grasses, alpines and small bulbs for 5-10 cm soil depth.
- Mixture of low or medium perennials, grasses, bulbs and annuals from dry habitats, wildflowers and hardy sub-shrubs for 10-20 cm soil depth.

Although rooftop vegetation improves run off water quality (Berardi et al. 2014), air quality (Dvorak, Volder, 2010) and reduces heat waves in a particular area (Cook-Patton, Bauerlev, 2012), it should be noted that rooftops are not a natural habitat for plants and all species are generally not grown due the major limiting factor being water. Considering all the environmental conditions on the rooftop, the following are characteristics of the type of vegetation for extensive green roofs;

- Ability to endure extreme climatic conditions e.g. drought
- Less maintenance
- Ability to survive under minimal nutrient conditions
- Should have short and soft roots
- Good enough ground coverage
- Ability to multiply rapidly
- Ability to reduce toxic effects of contaminants in the environment

It is rather quite difficult to find a plant species which possesses all such characteristics. However, there has been great progress in identifying a suitable kind of vegetation for green roofs (Dvorak, Volder, 2010, Farrell et al., 2012). The most common type of vegetation examined intensively was succulents. From the different types of succulents, sedum species are known to be used extensively around the world due to their ability to limit transpiration and store excess water in leaves and stems. This enables them to survive drought like conditions (Vijayaraghavan, 2016).

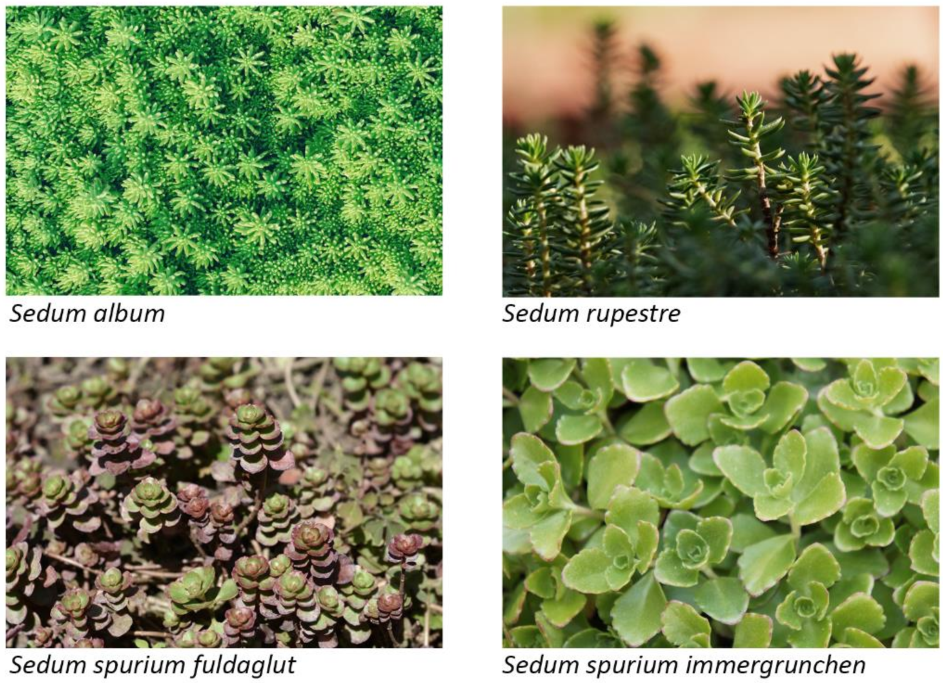


Fig. 11 Sedum species usually used on extensive green roofs. (Zakrisson, 2019)

2. Growth substrate

The growth medium plays a major role in the construction of a green roof. It is responsible for the life and success of the green roof. Therefore, it is crucial to select a suitable substrate for the plant growth. Most of the benefits of green roofs are directly related with the properties of the substrate which include; water quality improvement, peak flow reduction, sound insulation and thermal benefits. Because of harsh conditions that prevail on rooftops, it is necessary for the substrate to have other unique properties like having a good ratio of organic minerals that aid in plant growth, and being light weight. It is not possible for a substrate to possess all such properties, therefore it is common practice to combine several components with different properties in predetermined ratios to form a growth medium (Vijayaraghavan, 2016).

Commonly, commercial subsrates are used. However, there are researchers who have suggested alternate low cost and light weight materials that can be utilised in the growth substrate. (Vijayaraghavan 2015, Zhao M et al. 2014, Bates 2015). These materials include pumice, zeolite, scoria, vermiculite,perlite, peat and crushed brick among others (Vijayaraghavan, 2016). To make the green roof cost effective, it is recommended to use local waste materials. For countries where green roof materials are not available commercially, local soils are used for their construction. However, it comes with some cons such as poor water retention, increased weight imposes the risk of the collapsing of the roof, increases local weed growth which leach nutrients and compacting of the soil (Xiao M. et al. 2014). Therefore, the growth substrate should not be a 100% of local mix and should be engineered the correct way in order to achieve benefits from the green roof.

The growth substrate contributes majorly to the weight of a green roof. Therefore, it is advised to have the growth substrate as light as possible to avoid the destruction of the structure. For the case of old buildings with a green roof, it is recommended to use low bulk density growth substrate to avoid the risk of the structure collapsing. This can be achieved by using inorganic recycled materials with lower densities in the growth medium (Vijayaraghavan, 2016). The bulk density of perlite is 9.4 times less than the density of normal garden soil (Vijayaraghavan, 2014). Using perlite can reduce the weight of the green roof. It should also be pointed out that the lower the density of the medium, the thicker the substrate layer can be designed allowing a wide range of plants to be grown (Xiao M. et al. 2014).

For better performance of the green roof, the growth substrate should have a high absorption capacity and low leaching rate to be able to retain nutrients from the organic constituents which help the plants grow. Examples of the organic elements include mulch and peat among others (Kotsiris et al. 2013, Nagase et al. 2011). However, it is not recommended to use a large percentage of organic mixtures since they have been known to be the likely source of contamination in the green roof run off due to the unstable properties of the organic materials which breakdown over time causing the substrate to shrink (Rowe, 2011, Van et al. 2009). The desired amount of organic matter in the green roof substrate should only be 4-8% for extensive roofs and 6-12% for intensive green roofs as suggested by the German guidelines for green roofs (FLL) (Shafique et al. 2018).

The water holding capacity (WHC) of the substrate in the green roof is important for the optimal survival of the plants under drought like conditions. High WHC of the substrate can also allow for the growth of non-succulent species (Vijayaraghavan, 2016). For extensive green roofs, FLL recommends WHC to be greater than 20% (FLL, 2002). Increase in water holding capacity corresponds to the increase in substrate volume, depth and organic content; however, changes the substrate properties. Research has shown that the use of additives enhances the water holding capacity in the substrate (Beck et al. 2011). It was observed by (Cao et al. 2014) that the use of biochar as an additive enhanced the WHC as well as plant available water (PAW). Furthermore, (Farell et al. 2013) proved that the use of silicate granules and hydrogel also increased the WHC and PAW of the substrate in the green roof. The growing substrate should also have good aeration and flow properties also known as air filled porosity (AFP) to prevent roof leakage in case of rains and storms (Shafique et al. 2018).

As mentioned above, the growing substrate of a green roof should be designed effectively in order to achieve maximum benefits. For the substrate to be effective, the following are the desired characteristics of the substrate for extensive green roofs (Vijayaraghavan, 2016).

- High water holding capacity (WHC)
- Low bulk density
- Minimal organic content
- High air filled porosity (AFP)
- High hydraulic conductivity
- Less leaching and high sorption capacity
- High stability
- Good anchorage and support wide range of plants

3. Filter layer

The filter layer's role is to separate the growth medium from the drainage layer. It prevents small media particles such as plant debris and soil fines from entering and clogging the drainage layer. Generally, geotextile fabrics are used as filters in the green roof (Townshend, 2007, Vijayaraghavan, 2015). The tensile strength of these filter fabrics is usually high in order to withstand the substrate and vegetation load. In addition, the filter fabrics have small pores to allow good water permeability into the drainage layer while preventing the entry of soil particles. The filter layer also acts as a root barrier membrane for plants which have short and soft roots (Vijayaraghavan, 2015). Rersearch showed that non-woven geotextile filter fabric absorbed 1.5litres of water per square meter (Wong et al. 2014). This characteristic improves the water retention capacity of the green roofs. Moreover, the filter fabric should be thick to allow excess water retention. It was identified by Licht and Lundholm that green roofs with thicker filter fabrics retained more than 300% water compared to green roofs without the filter fabrics. Therefore, it is important to select the right filter fabric for enhanced performance of the green roof.

4. Drainage layer

The drainage layer is one of the most important layers in the performance of a green roof. It serves as a balance between air and water in the green roof system. The drainage layer allows the removal of excess water from the growing medium keeping it light weight which reduces the chances of the collapsing of the structure. The drainage layer is also responsible for the protection of the waterproof layer and improving the thermal properties of the green roof (Townshend, 2007). There are two major types of drainage layers used in the green roof system in recent times.

- Drainage modular panels: These panels are made of polyethelene or polystyrene which are high strength plastics. They have sections where water is stored while allowing the excess to be drained.
- Drainage granular materials: These are materials such as light-weight expanded clay aggregates (LECA), expanded shale, crushed brick, coarse gravel and stone chips which have large pore spaces to store water and have some water holding capacity.

It is necessary to consider the cost, construction requirements, vegetation type and the scale of the green roof before selecting a suitable drainage layer. Generally, granular materials are suitable for small scale projects such as residential buildings as they are able to store more water in their compartments. However, granular materials can only be used in flat roofs or roofs with a slight angle of less than 5 degrees. On the other hand, for large scale projects, drainage modular panels are preferred since they can be used on both flat surfaces and moderately sloped ones. The downside of the drainage layer is the cost and the difficulty in disposal of the materials, but due to their easy installation and modification, they are favoured to use in green roofs (Vijayaraghavan, 2016).

5. Waterproofing layer and root barrier

As all the other layers, the waterproofing layer is also crucial in the success of a green roof as it prevents water leakage. The water content in the substrate and the drainage layer is usually high. Therefore, there is a possibilty of water leakage and in order to find the the leak, all the layers need to be removed. Hence, it is necessary to apply the waterproofing layer in the green roof system (Vijayaraghavan, 2016). Examples of waterproofing membranes include liquid applied membranes, single ply sheet membranes, modified bitumen sheets and thermoplastic membranes (Townshend, 2007). The kind of waterproofing layer is determined by the cost, life span, availability in the market and the type of green roof (Vijayaraghavan, 2016).

The root barrier layer is not mandatory for extensive green roofs, however it is required for intensive green roofs. The role of the layer is to prevent the roots of the plants to penetrate through the layers reaching the roof deck. There are many root barrier materials available in the market including hard plastic sheets and copper sheets among others (Vijayaraghavan, 2016).

2.5 BENEFITS OF GREEN ROOFS

As much as green roofs are aesthetically pleasing, they also provide multiple environmental, social and economic benefits. The benefits translate to the ecosystem services provided by green roofs. Generally, higher ecosystem services are provided by urban vegetation grown on land. However, due to intense urbanization, the green spaces on the ground level are becoming scarce. Therefore, green roofs play a vital role in providing ecosystem services which mostly contribute to environmental sustainability. The benefits are further explained in detail below.

1. Management of storm water.

In urban areas, green roofs are vital in storm water management since most urban areas are dominated by hardscapes and contribute to excess storm water run off which causes environmental problems such as reducing water quality by infiltration of urban pollutants, erosion of river banks and flooding (GSA, 2011). Green roof is an ideal alternative for storm water management since it has the ability to store water and prevent water runoff.

During rainfall season, the vegetation and substrate layer absorb and store excess water reducing the chances of flooding and aid in reduction of stormwater runoff. The runoff and retention is determined by factors such as vegetation type, thickness of substrate, type of drainage layer, roof slope and intensity of rainfall. There have been studies that prove high water retention by green roofs. Data showed that for a roof slope of 2^0, with a rainfall intensity of 0.4mm/min, the water retention was 62% and for an intensity of 0.8mm/min, the roof slope of 2^0 retained 54% of rain water (Villarreal and Bengtsson, 2005)

The substrate should possess high water holding capacity (WHC) for storage of more water (Shafique et al. 2018). Vegetation is also important for water retention since every plant has its own water retention and evaporation capacity (Razzaghmanesh, 2014). Studies show that grasses hold the most amount of water (Shafique et al. 2018).

2. Mitigation of Urban Heat Islands

As mentioned above, urban areas are dominated by hardscapes and replaced vegetation. Due to the increased number of buildings and other dark surfaces, these areas contribute to urban heat islands where the urban areas are warmer than the surrounding suburban and rural areas (Oberndorfer et al. 2007).

Urban heat islands are one of the causes of air pollution, increased energy consumption and higher rate of illnesses (GSA, 2015). The temperature levels of urban areas is said to have risen 8^0C more than the neighboring areas during the summer (Kuhn, 1999). To mitigate this effect, introduction of green roofs as vegetation is a beneficial solution.

Through evapotranspiration or evaporation of water from the soil and transpiration in plants, the green roofs absorb less sunlight and cools the building especially in the summers. Green roofs also store water which is another reason that can cause temperature to reduce and cool the building. Additionally, green roofs can act as insulation which aids in summer cooling since plants reflect heat energy. In fact, there have been studies which show that the temperature of green roof surfaces is around 4^0C cooler than the temperature of black surfaces in the summer (GSA, 2015). Therefore, implementing green roofs widely around the city can reduce the effect of urban heat islands.

3. Habitat and biodiversity

Another benefit of a green roof is that it acts as home for flora and fauna. Biodiversity means a variety of plants and animals in an area. Green roofs are a means of providing a habitat in urban areas for plants and animals including birds, insects and invertebrates. This increases biodiversity and in turn helps ecosystems to continue functioning (GSA, 2015).

4. Energy saving

One of the significant benefit of green roofs is energy efficiency which in turn leads to saving of energy costs. Energy consumption of buildings with green roofs is reduced by the process of evapotranspiration (as mentioned above), shading, increase in thermal mass and insulation. In the summer, green roofs can reduce the heat from solar radiation in a building resulting in reduced needs for air conditioning and in winters, they act as insulation which retain the solar heat gains of the day. Variables such as climate, type of green roof, height of the building and surrounding buildings, moisture on the roof and temperature change constitute to the determination of the amount of energy saved (GSA, 2015).

Studies have been conducted that depict the reduced consumption of energy in buildings with vegetated roofs. A building with a vegetated roof in Singapore showed a 10% decrease in heat transfer on a typical day compared to a grey roof building (Wong et al. 2003) whereas in Japan, the reduction of heat flux per year was 50% (Onmura et al. 2001). These statistics prove that implementation of green roofs is a benefit for energy saving ergo saving energy costs.

5. Reducing air pollution

One of the effects of urbanization is air pollution caused by emissions from buildings, cars, industries among other sources. Construction of green roofs in urban areas is an approach to mitigate air pollution and improve air quality. Trees and plants have generally been used on ground as a means of eliminating air pollutants and greenhouse gases such as carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide and particulate matter (GSA, 2015). Similarly, plants and trees on green roofs would aid in removing air pollutants. The type of plants grown on roofs and the depth of the soil contribute to the effectiveness of the green roof in mitigating air pollution. Intensive green roofs are generally considered to be able to reduce air pollution due to their ability to house larger plants and trees.

Evaluating the elimination of pollutants on green roofs can also be related to the benefit of energy saving and mitigation of urban heat island (Berardi et al. 2014). Since green roofs enable reduction in energy consumption, the level of carbon dioxide and other industrial air pollutants is potentially reduced, thus improving air quality.

6. Sound insulation and acoustics

Another benefit of vegetated roofs is providing sound insulation. Green roofs have sound absorbing capacity. Compared to non- vegetated roofs, buildings with green roofs in urban areas can reduce noise pollution arising from the surroundings, i.e.: vehicular traffic. Based on a study to measure the noise level, it was indicated that green roofs reduced the noise frequency by 10 and 20 decibels (Connelly and Hodgson, 2013). However, the reduction of sound levels is mainly affected on the upper floors of a building.

7. Rooftop agriculture

Farming on rooftops contributes to social, environmental and economic sustainability. The carbon emissions associated with the production and distribution of food items commercially can significantly be reduced by growing crops on rooftops. It also enables the access of fresh products for building occupants on a daily basis. In contrast to farming on ground, rooftop agriculture limits the invasion of pests and rodents. In addition, farming is labor intensive; thus rooftop agriculture can provide job opportunities. The soil thickness should be considered when planting certain crops. Plants like kale, spinach and lettuce have been recorded to be grown in modular setting of a green roof. However, other plants can be grown depending on the climate of the particular area and soil type and thickness. Another

Fig. 12 Eagle street rooftop farm, Brooklyn, New York, USA.
Retrieved from rooftopfarms.org Dec. 2021

advantage of urban rooftop farming is that it can potentially increase the value of the property by providing additional services (GSA, 2015).

8. Aesthetics and Social benefits

Green roofs in general are pleasing to the eye. Both extensive and intensive green roofs create aesthetic and attractive spaces for inhabitants and neighboring viewers. Vegetated roofs can act as recreational and socializing spaces that are relaxing and bring people together. Presence of plants is known to reduce stress levels, lower blood pressure and increase working productivity. Green roofs can be designed with seating areas and other functional activities for the users. Buildings with green roofs hold a higher value compared to those without green roofs.

9. Economic benefits

The initial construction of green roofs may seem costly, however in the long run it is quite cost efficient. The type of green roof system, the waterproofing layer and the kind of plants used are some of the factors that help determine the economic benefits. Green roofs contribute to energy cost savings due to the insulation and thermal resistance properties which limits the use of HVAC systems. As mentioned above, the property value and marketability of a building with green roof can be higher especially in urban areas where there is lack of green spaces (nps.gov, 2021) which may results in faster sales and occupancy of the building.

10. Roof longevity

Another one of the benefits of installing a green roof is the lifespan of it. Compared to a conventional roof, a properly installed green roof can survive longer before it needs replacement. The reason for this is because the vegetation layer and the growing substrate protect the roof membrane from direct UV rays and manage to regulate the building temperatures. Studies have shown that a green roof can last up to 40 years or more depending on the maintenance in contrast to a black roof whose life expectancy is 17 years (GSA, 2015).

2.6 CONSTRAINTS OF GREEN ROOFS

Rated as a prospective pollution regulatory amenity, a green roof can also act as a recovery mechanism of natural hydrology in metropolitan areas. Multiple other investigations reveal economical, social and environmental advantages (Shafique et al. 2018), however in people's opinion, green roofs have numerous limitations. Generally, cost, construction damage, servicing and leakage are the most notable setbacks and in the absence of government rulings, green roofs are an impractical architectural feature especially in developing countries. The assembly of green roofs is considered expensive and the yield futile, and on top of that, further expenditure is incurred in the care and eventual destruction (Biancini and Hewage, 2012).

According to different physical illustrations conducted in three different sites in the United States for durations between 11 and 60 years, green roofs are nonetheless calculated to be more expensive relative to normal roofs, while taking into account may factors, for instance, life span of the roof, reserving energy and rainwater collection. However, the greater part of these analyses do not give regard to cost-benefit studies. Furthermore, computing measurements of refinement of air standards or decrease of UHI impact are remarkably complicated proceedings, while the advantages like ecological conservation, aesthetics and decreased commotion are subjective to individual preference (Vijayaraghavan, 2016).

Relative to the unsatisfactory returns, initial setting up costs of green roofs are worked out to be the main obstacle. Contrary to this popular belief, trials involving cost benefit analysis in Washington uncovered that green roofs are in actuality competitively economic compared to the standard roof (Shafique et al. 2018). Nurturing green roofs with irrigation and fertilized feed and periodic controls of drainage, plant and substrate health are critical factors to prolong the life of a healthy green roof in optimum weather conditions, and as opposed to the misconception, maintenance of this type of roof requires continual input and effort (Shafique et al. 2018). A well-ordered management is needed to attain a successful green roof and therefore, a joint effort of architects, civil and environmental engineers and agriculturalists is required for the project to thrive (Shafique et al. 2018).

Most of the exploration of green roof projects is concentrated in the USA and parts of Europe, while Australia and few other countries in Asia continue to participate in such studies. Local research plays a significant role in bringing about awareness of interest and multiple benefits of green roofs, as well as putting forward more concerns to consider, for example, in South Korea, run off water was found to be of toxic due to excessive amounts of fertilizer being used on the green roof (Shafique et al. 2018). Additionally, the most considerable environmental complication is that the polymer constituents of the green roof cause an increased greenhouse effect due to high carbon emissions during production, therefore raising sustainability concerns (Biancini and Hewage, 2012). However, due to load constraints on roof systems, polymeric elements are ideal materials to be used in green roof construction, especially as lightweight components (Vijayaraghavan, 2016).

Further complications related to green roofs are structural damages caused by leakage. Improperly fitted components of green roofs are the source of destruction and failure of other parts of the building or building materials (Shafique et al. 2018). The presumption is that green roofs are twice as durable as conventional roof types if correctly installed

(Kosareo and Ries, 2007) for the reason that the water-proof membrane is shielded from mechanical destruction as well as UV, heat and cold waves (Vijayaraghavan, 2016).

To summarise, the general constraints of a green roof are listed below:

- Cost of installation
- Maintenance issues
- Question of being sustainable
- Structural damage
- Water runoff quality
- Limited research for developing areas
- Roof leakage
- Dismantling and disposal

CHAPTER 3

CASE STUDIES

CASE STUDIES.

This chapter involves extensive research and analysis of case studies of buildings with green roofs in three different cities across the world namely; Nairobi, Turin and Istanbul respectively. The choice of selection of these cities is based on their geographical location and climatic conditions which are the main variables to be considered in the implementation of green roofs. All three cities are metropolitan cities with increasing urban development. However, there are multiple differences in the application and management of green roofs in these cities. The case studies provide a deeper look into the similarities and differences in the implementation of green roofs in terms of city urbanization, climatic conditions, type of construction, social and architectural conditions, and regulations or policies.

3.1. NAIROBI

Nairobi being the capital city of Kenya, is situated on the South-central part of Kenya and is one of the fastest growing cities in the world. With a total area of 696 km^2 (Kenya census, 2019), it is located in the southern part of Kenya's agricultural mainland and about 480km away from the Indian Ocean (Figure 13) (Mbatia 2016). Nairobi is branded as the "green city in the sun" mainly because it is built on land of rainforests and savannah grasslands with many rivers passing through it (Smart Cities Dive, 2021). However, the increase in built environment through the years has replaced a lot of greenery. This is due to the increase in population and the migration of people from rural areas to the city in search of a better life. Nairobi city has one of the highest growth rate among any other city in Africa. From its establishment in 1899, Nairobi being one of the youngest cities in the African great lake, has become the second largest city in the region (worldpopulationreview.com, 2021) with the highest recorded population in the country. The growth rate of the city per year is said to be 4%. The current population of Nairobi is

4.9 million people. With the increasing growth rate, the population of Nairobi by 2025 is estimated to increase by another million (worldpopulationreview.com, 2021).

The increase in population in turn demands for increase in development and urbanization in Nairobi which compels the need for deforestation. The most recent development that forced the cutting down of hundreds of trees is the construction of a raised highway. Statistics show that the forest covers in Nairobi went from 14% to 3% and bushland covers fell from 22% to 13% between the years 1976 and 2000 (The conversation, 2021). This has had an effect on climate change, city's biodiversity and the green public space. Figure 14 and 15 depict the difference in built environment and green area in the city of Nairobi between 1984 and 2016.

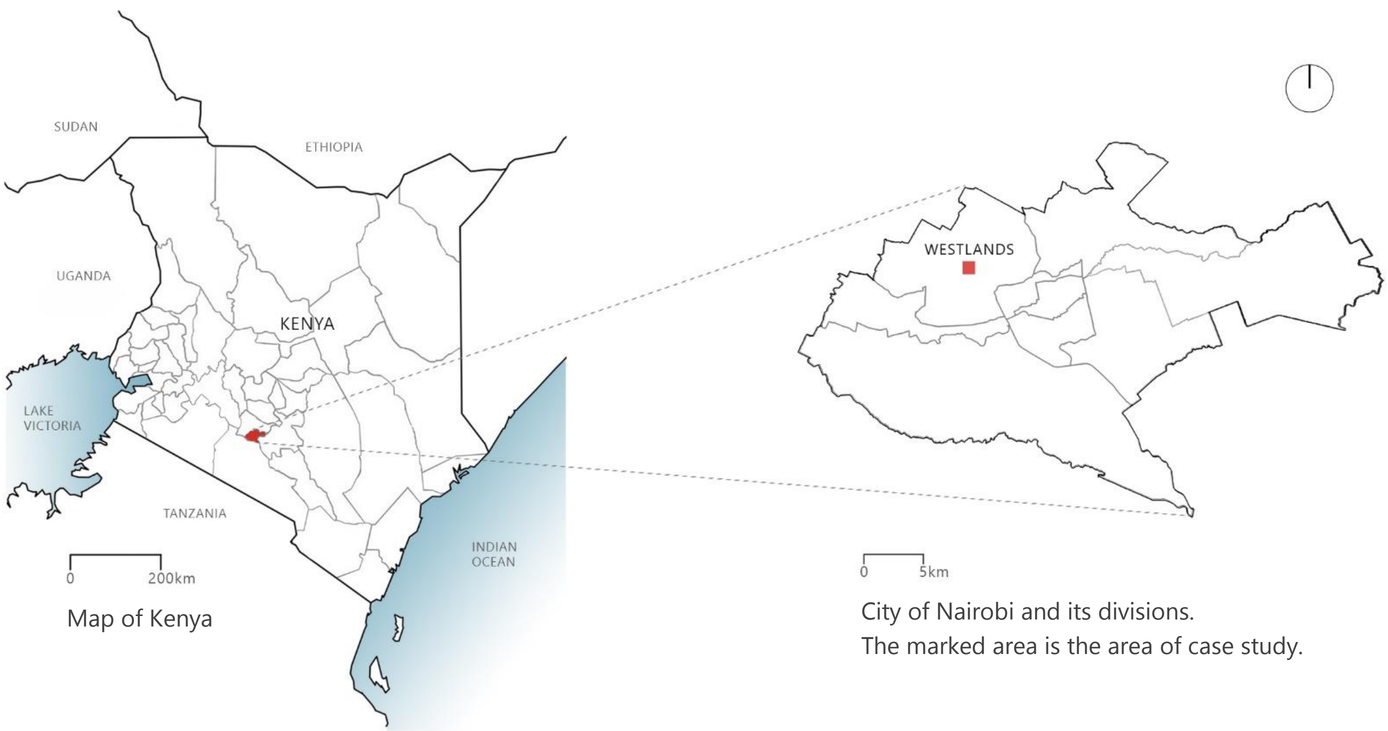


Fig. 13 Location of City of Nairobi
By Author, referenced from google maps.

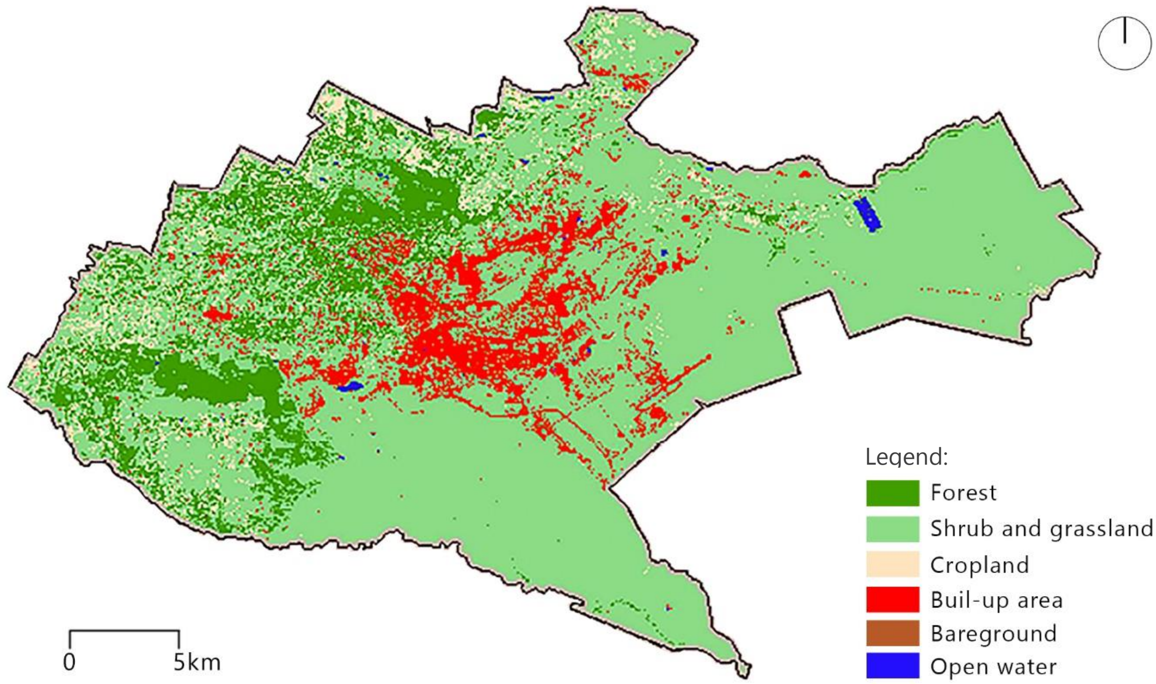


Fig. 14 Land cover map of Nairobi in 1984
Adapted by author from (Abuje et al. 2020)

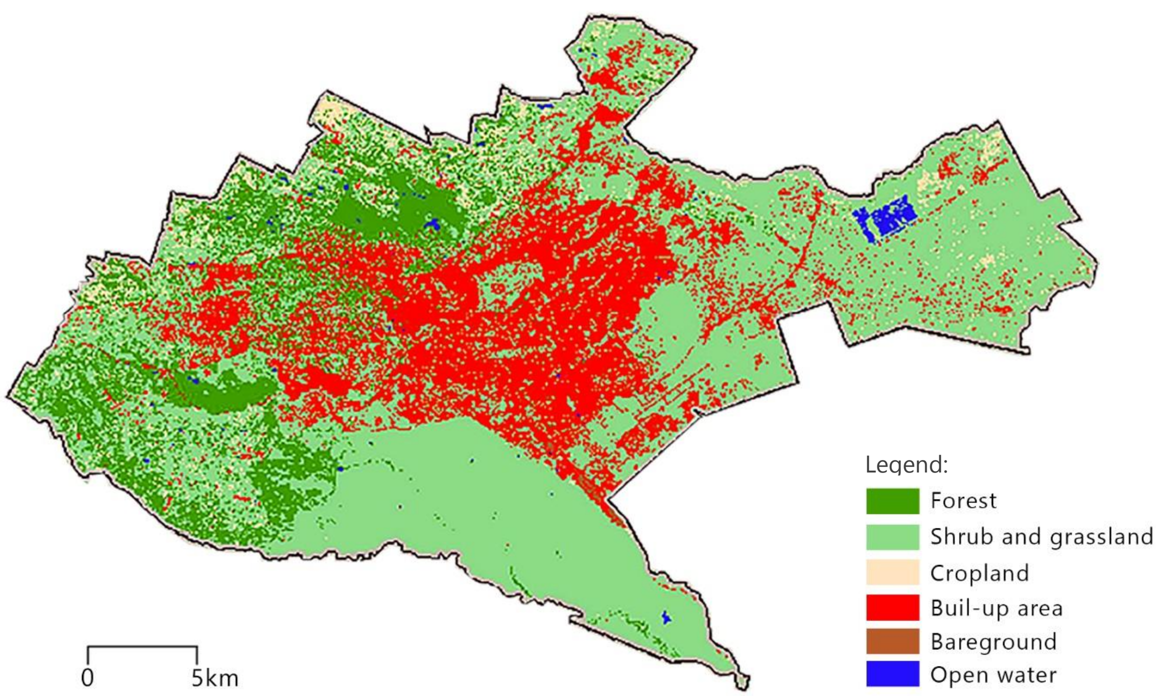


Fig. 15 Land cover map of Nairobi in 2016
Adapted by author from (Abuje et al. 2020)

1. Climate analysis

Nairobi's climate is classified as a subtropical highland climate under the Köppen climate classification (Gaita et al 2016), where it is hot and dry during the day and cool in the mornings and evenings on the months of May to August. Nairobi experiences the warmest and sunniest times from December to March with an average temperature of 24ºC (Kimote 2020). There are two rainy seasons in Nairobi and the cloudiest times of the year is after the rainy season which lasts until September (Kimote 2020). The difference between the dry and wet seasons in Nairobi is minimal due to the fact that the city of Nairobi is situated close to the equator, and for the same reason, Nairobi does not experience the 4 seasons. Hence, the variance in timing of sunrise and sunset is slight.

1.1. Precipitation

Nairobi experiences rainfall in 2 periods every year; short rains and long rains. The short rains occur during November to December with rainfall of 120 mm and long rains between the months of March to May with an average of 155 mm in the wettest month (April). Nairobi receives a good amount of rain even in the driest month. The driest month is July with a precipitation of 12 mm (Nairobi climate data, 2022).

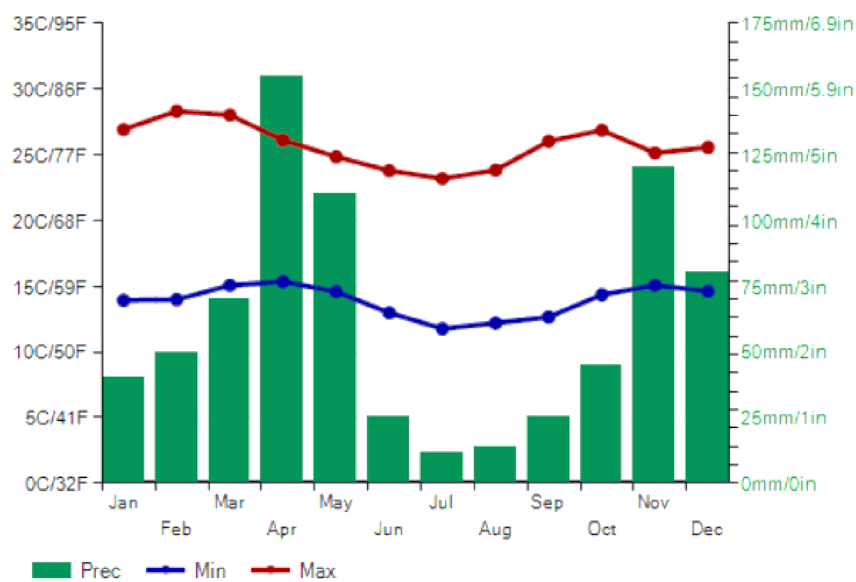


Fig. 16 Average temperature and rainfall of Nairobi
Retrieved from Climatestotravel.com (2022)

1.2. Temperature and Sun path

Temperatures in Nairobi do not reach extreme levels. The coolest month is July with an average temperature of 17.5°C and the warmest month is March with an average of 21.5°C (Nairobi climate data, 2022). The maximum and minimum temperature of each month is shown in fig 16. Over the period of 1979 to 2015, Nairobi's daily maximum and minimum temperatures show a distinct, statistically significant linear warming trend in all seasons of the year of between 0.3 and 0.4°C each decade. Looking more closely at how the temperature changed over time, daily maximum temperatures generally decreased slightly during the 1980s after which the trend is positive and most strongly positive during the 1990s especially during the warmest time of the year which is from January to March (Urbanark, 2017).

The warmest months have the longest hours of sunshine. January, February, November and December have the longest hours of daylight which is 12.2 hours and June has the shortest daylight days of average 12 hours. The most sunshine is in the months of January and February with an average of 9.6 hours and the least sunshine is in the months of April and May with an average of 8.5 hours a day (weather-atlas.com, 2022).

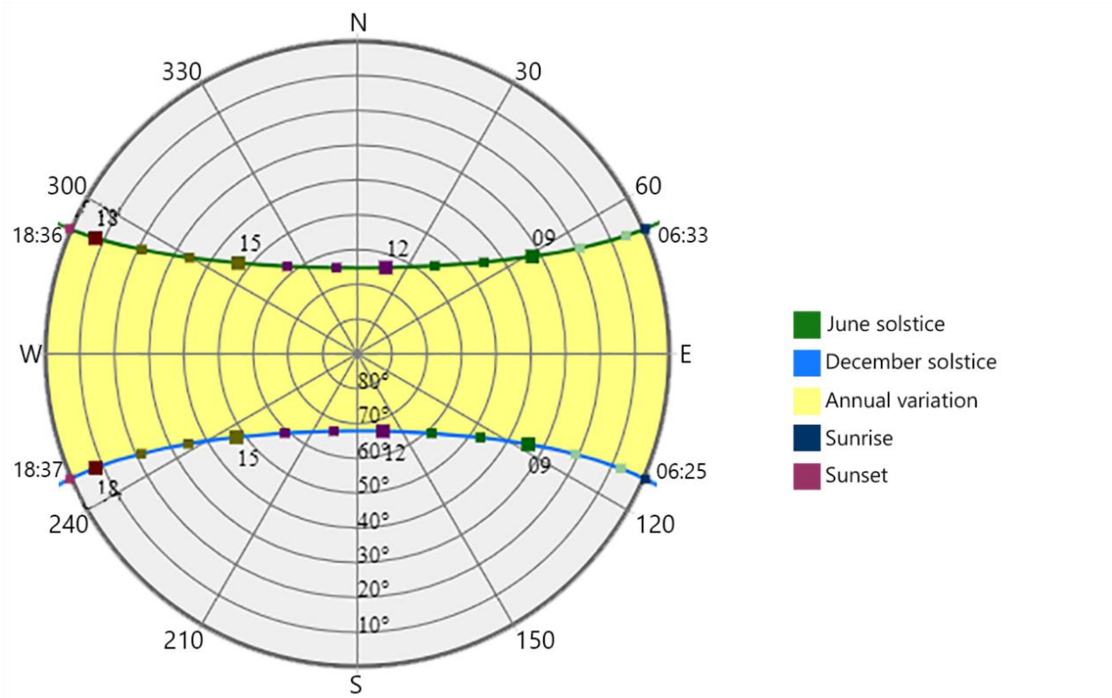


Fig. 17 Stereographic sun path diagram of Nairobi
Retrieved from gaisma.com (2022)

2. Air pollution

Nairobi is occupied by around 4.3 million people within the city limit. It is a hub for many business centers and factories. It is not surprising that Nairobi suffers from air pollution as a result of these business activities and the sheer number of people. The main pollutant type in Nairobi is particulate matter 2.5; PM2.5. According to IQAir (2022), Nairobi's average PM2.5 concentration in 2020 was 14.7 μg/m3, which is approximately 1.5 times the recommended annual PM2.5 threshold concentration of the World Health Organization (WHO). The most polluted month in 2020 was July, with an average PM2.5 concentration of 22.6 μg/m3 (IQAir, 2022). In general, Nairobi's daily air quality fluctuates between good and unhealthy levels (IQAir, 2022).

The main causes of pollution in Nairobi are related to the mass movement of people and combustion. Vehicles are responsible for a large amount of pollution in the city of Nairobi.

In particular, heavy duty vehicles such as busses and trucks pollute the environment due to their consumption of diesel. Another significant cause of pollution is from factories and industrial areas which emit fumes. This affects the health of the people if released in large amounts and not considering the regulations for safety. These two causes are the biggest sources of pollution in Nairobi.

When it comes to pollutants, besides PM2.5, pollutants such as nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) would be present in areas with high vehicular activity. Other pollutants include fine particulate matter from construction sites, such as black carbon or finely ground silica. Micro-plastics, as well as dangerous metals like mercury, cadmium, and lead, could be found in the air. Volatile organic compounds (VOCs) are found in any area where there is burning or combustion, and some of them are dangerous chemicals like benzene, xylene, or formaldehyde. These are just a few of the many pollutants found in high-pollution areas around Nairobi (IQAir, 2022).

A strategy to reduce the levels of pollution in the city is to implement green roofs. Trees and plants are generally used as a means of eliminating air pollutants and greenhouse gases such as carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide and particulate matter (GSA, 2015).

3. Urban Green Areas in Nairobi

Nairobi has several natural urban green areas. However, the spatial distribution of these urban green areas is uneven (Mbatia, 2016; M'Ikiugu et al., 2012). Figure 16 shows the spatial distribution of the green areas which as seen, are mostly concentrated on the western part of the city. Nearly twenty one percent of the Nairobi city, which is about 147 square kilometers has been allocated by the county council for natural green spaces (Mbatia, 2016). The vegetation in Nairobi includes a variety of biodiversity (Shah and Ayiemba, 2019). The largest urban green space is the Nairobi National park which is a natural reserve and includes wildlife and a forest. In addition, Karura forest and Ngong forest are also natural urban green spaces with biodiversity and parts of it are accessible to the public for recreational purposes. Besides these natural green spaces, there are a few other natural urban green areas and parks like Uhuru Park and City Park which are mostly located in the western part of the city where the upper middle class reside (Kimote, 2020).

As mentioned in the introduction, Nairobi was given the title of the green city in the sun due to the presence of savannahs and rainforests. The city has now probably lost that name because of the increased urbanization replacing most of the natural vegetation. The urbanized land of the Nairobi accounts for only 48%. The built area of Nairobi which includes commercial, residential, industrial activities, and institutional land uses is roughly less than half of the city's total land area (Mbatia, 2016). The remaining half of the Nairobi's land is covered by open spaces either privately or publicly owned (Kimote, 2020). The maintenance of the public green spaces in the city is usually difficult. There also have been attempts to grab the public green spaces for private development, some successful, which prove the shrinkage of the public urban green areas in the city (The grid, 2022).

Kenya's government has plans and projects to be implemented to shape the city before vision 2030 (Kimote, 2020). Therefore, the future of urban green spaces and planning is in the hands of the Nairobi County government, city managers, the national government and the residents of the city. The vision 2030 for Kenya calls for greener and sustainable cities. Nevertheless, with the rapid increase in urbanization, the question is, will the city of Nairobi balance its green spaces with the urban built up space?

4. Green roofs in Nairobi

Due to the urbanization effects and climate change, one of the strategies to create a sustainable environment is the application of green roofs which comes with several advantages. Green roofs in Nairobi are few in number and the accessible existing ones are located in the upper middle class and commercial areas (Kimote 2020). The concept of green roofs is not widely known by the people of Nairobi. Studies conducted by Kimote (2020) show that the residents in the city of Nairobi are barely aware of the existing green roofs in the city as well as their use and benefits since the green roofs exist in upper middle class region of Nairobi. However, they showed interest in acquiring knowledge about green roofs and implementing them in the future. Additionally, they assumed the construction and maintenance of a green roof is expensive.

There are currently about 6 known buildings with green roofs which fit the specified meaning of a green roof. Artificial green roofs, naturally grown vegetation on rooftops and pot vegetation are not considered part of green roofs.

The known buildings with green roofs in Nairobi are:

- Haveli Towers
- Morning side Office Park
- French Embassy
- Switzerland Embassy
- Rosylin drive
- Previous Coca-Cola building

The spatial distribution of the green roofs in Nairobi (Figure 19) shows that they are concentrated on the upper class commercial division with none on the other divisions of Nairobi just as the urban green spaces on ground. The focus of case study is on the French Embassy in Nairobi.

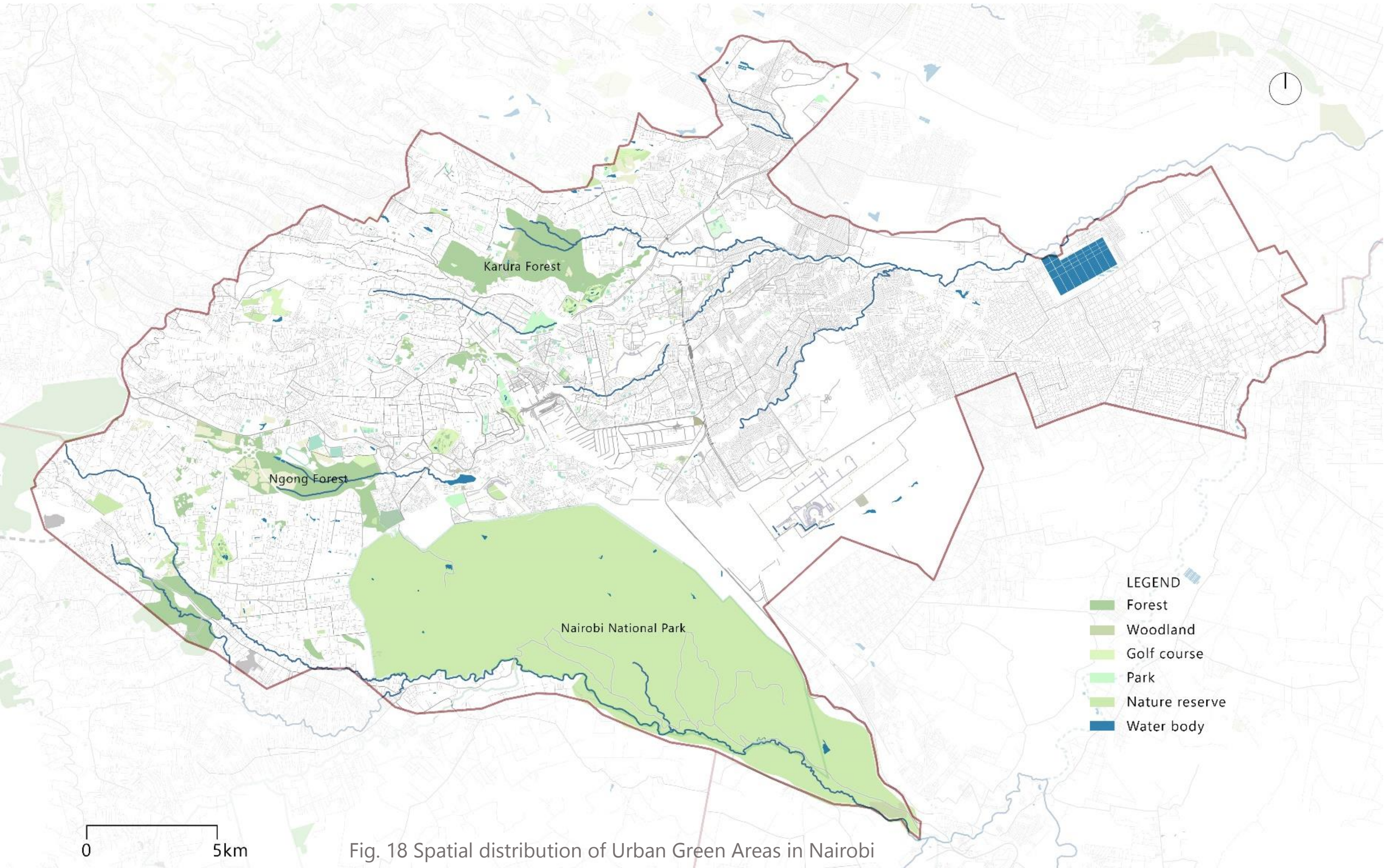


Fig. 18 Spatial distribution of Urban Green Areas in Nairobi
Adapted by author based on Google maps 2022 and Open Street Map 2022

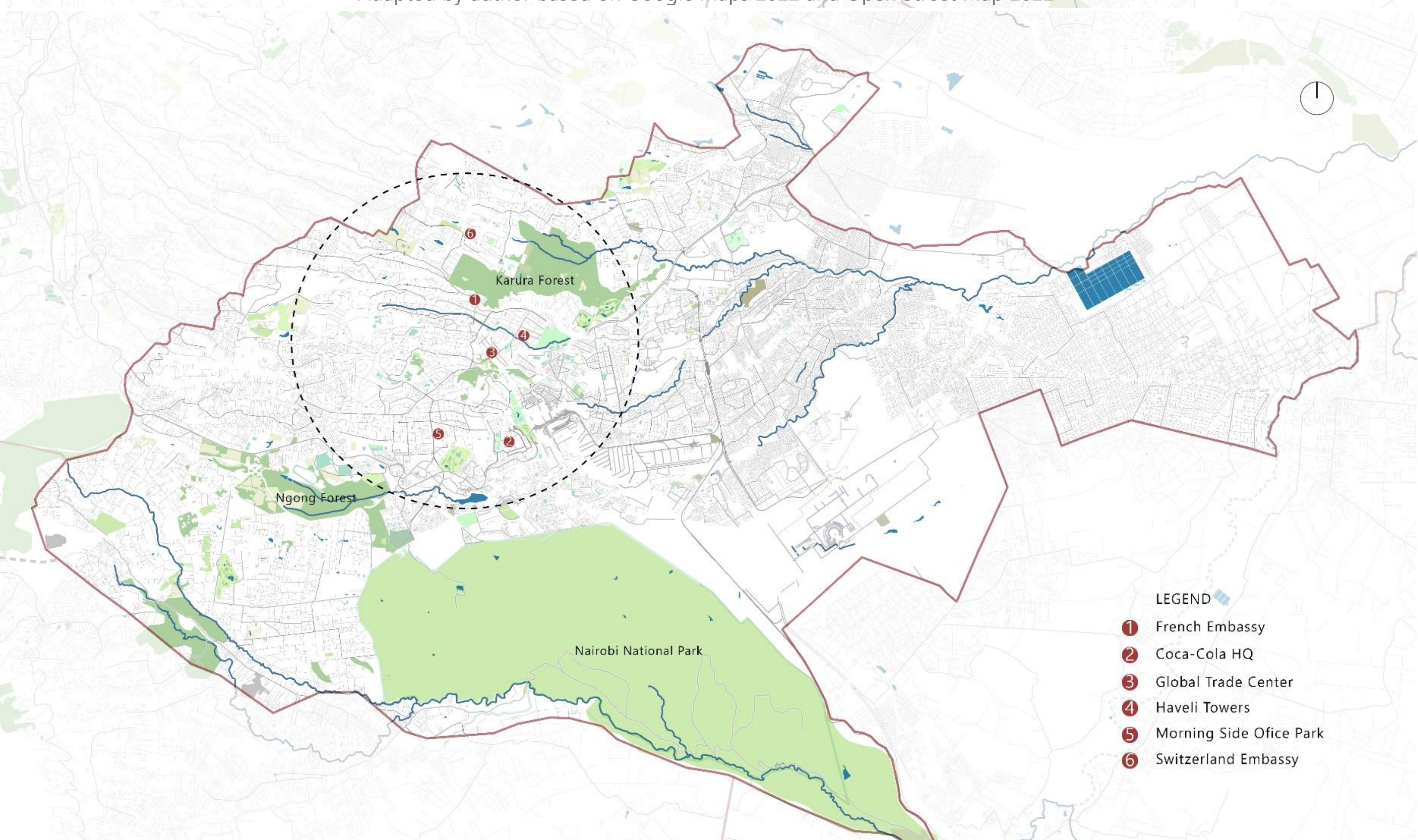


Fig. 19 Localization of existing known green roofs in Nairobi
Adapted by author based on Google maps 2022, Open Street Map 2022 and (Kimote, 2020)

5. **French Embassy Nairobi, Kenya**

One of the buildings with a green roof in Nairobi is the French Embassy building located in a mixed socio-economic zone in Westlands along Peponi road. The structure lies on a hilltop between two valleys falling towards the Getathuru River and, beyond that, Nairobi's Karura Forest. It is situated in a convenient location with quick access to services such as banks, restaurants, shopping centers, entertainment spots and residential area.

Fig. 20 French embassy site map (Google earth, 2022)

The building design of the French embassy in Nairobi has been adopted from the French culture. It was designed by Terreneuve architects from Paris, France alongside Phytolab Landscape and Pharos Architects in Nairobi. The project, with the area of 3224 m^2 began construction in 2015 and was completed in 2017 (terreneuve.fr, 2021). The project consists of the embassy and the ambassador's residence on which both structures have green roofs. The green roofs were implemented after the construction of the building in 2017. Figure 21 shows the site plan and section of the building design clearly portraying the sloped green roof. The green roof implementation provides an aesthetic architectural perspective on the building beautifying the area. The green roof is a sign of the efforts of the French government in biodiversity conservation both locally and internationally (Kimote 2020). The building was designed with the aim of providing environmental benefits such as stabilizing temperature in the buildings, increase wildlife habitat, decreases urban heat-island effect, slow rainwater run-off as well as aesthetics and security. The French embassy has received a LEEDS certificate for sustainability which was also one of the reasons of implementing the green roof as stated in an interview by Andrew of Pharos Architects.

Fig. 21 Site plan and section of the French embassy (Phytolab, 2022)

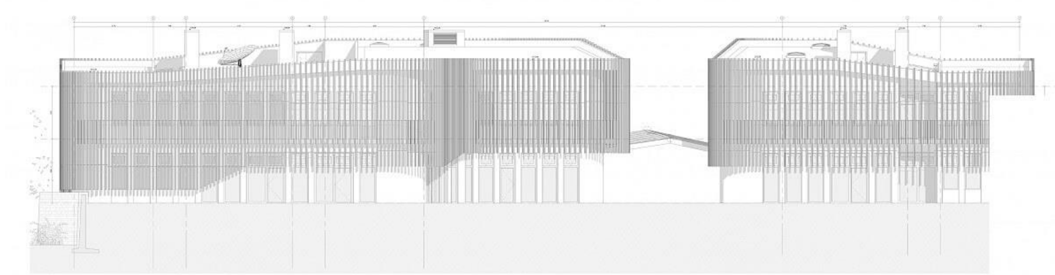


Fig. 22 West elevation of French embassy showing sloped roof (Terreneuve, 2022)

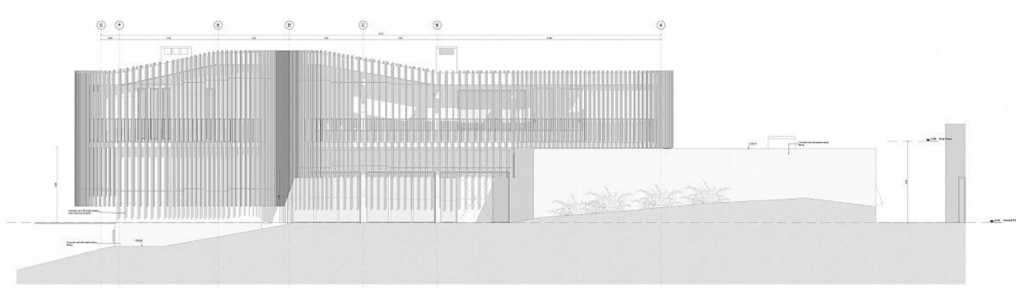


Fig. 23 West elevation of the Residence showing sloped roof (Terreneuve, 2022)

5.1. Vegetation cover

The green roof on the French embassy is classified as a semi-intensive green roof. The plant type used for the French green roof is a mixture of Sedum, succulents like local aloe as well as shrubs and grasses which do not require upkeep or regular watering. Sedum is a succulent plant belonging to the Crassulaceae family. It is found in cold arid and, or dry areas. The green roof of the French embassy building is highly resilient to diseases caused by pest attacks thus minimizes such incidents (Kimote 2020).

The vegetated roof was mainly designed for environmental purposes. In 2015, an environmental regulation was imposed by the French government mandating new constructions in the commercial areas to partially cover the roofs with vegetation or solar panels. These measures, which aid in sustainability and mitigation of climate change, were put in place in order to achieve the goal to reduce global warming from 2 to 1.5 degrees Celsius (Hulme 2016).

When designing the green roof, several factors including maintenance, cost, reliability and aesthetics were taken into consideration (Pharos Architects, 2022). According to Andrew, the main challenge was the availability of materials locally. The drainage layer in particular was hard to find and was imported from out. When asked about any kind of regulation or policies Andrew followed for designing the green roof, he mentioned that there are no current mandates or government policies on green roofs in Kenya.

When it comes to accessibility, the French embassy allows only authorized personnel in the premises thus the rooftop is not accessible to the public. The accessibility is only for maintenance purposes.

Fig. 24 French embassy residence green roof (Monocle, 2021)

Fig. 25 French embassy rooftop vegetation (pharos architects, 2022)

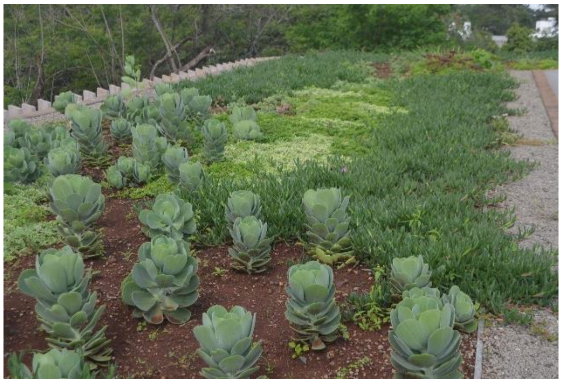


Fig. 26 Types of sedums, succulents and other vegetation on the French embassy green roof (pharos architects, 2022)

3.2. TURIN

The second case study is based in the City of Turin in Italy. The city of Turin is among the most populated municipalities of the country it is the fourth biggest city according to the national census of 2011 and is located in the northwest of Italy. It counts around 882,000 citizens distributed in an administrative area that spans about 130 km^2 (ISAT Italian Census, 2019).

The city lies 240m above the sea level and is surrounded by Northern and Western Alps. In the east and south, the city is bordered by hilly landscapes of Turin and Monferrato. The town is shaped by the evolution of the Po River and its tributaries which are mainly the Sangone, Dora, and Stura that cross the city (Salata et al, 2020).

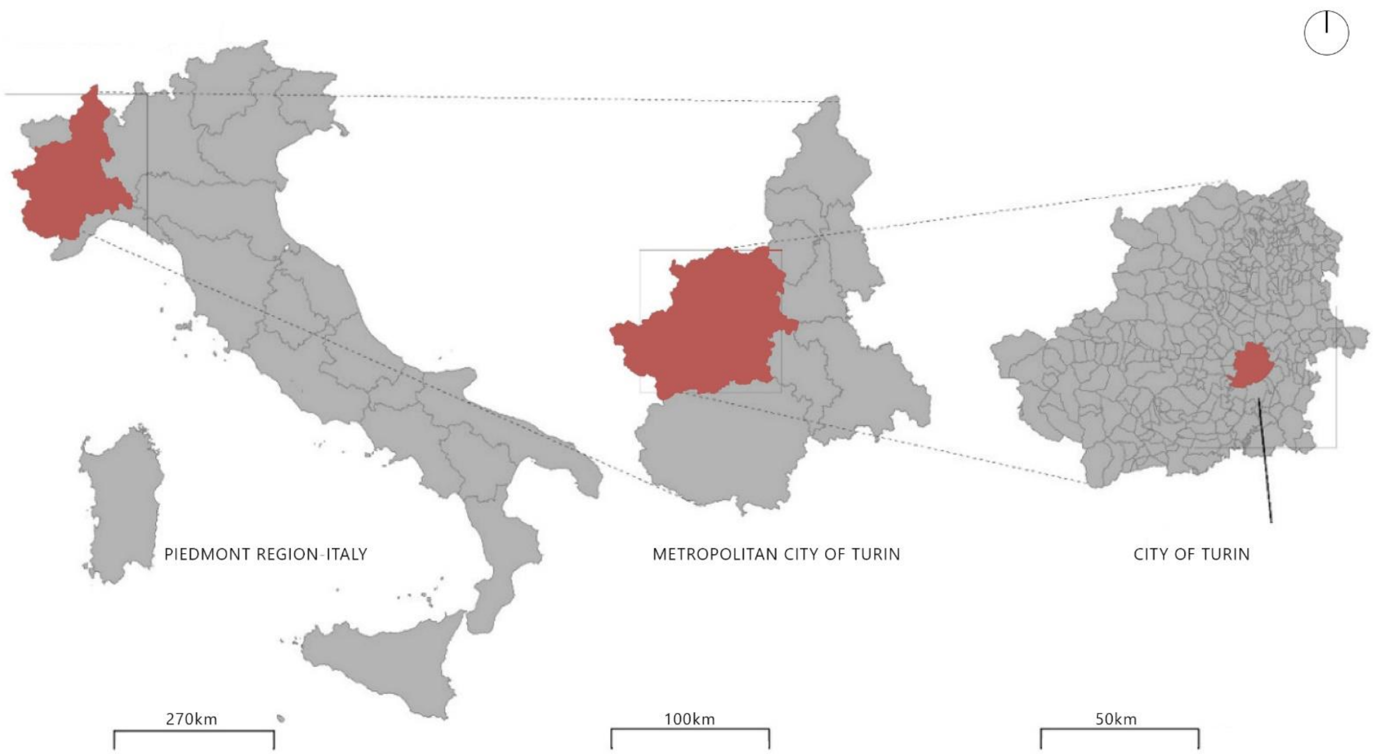


Fig. 27 Location of City of Turin
Adapted by author from (Salata et al, 2020)

The settlement system in Turin is densely constructed with compact urban development and a lot of impermeable areas. More than 7400 hectares of the city are sealed, with an average sealing rate of 57.55 percent, according to the Digital Topographic Geodatabase of 2018. (Calculated as the fraction of sealed surface on the total administrative area).

Turin is enclosed by high quality peri urban green areas where the structural connection of River Po to River Dora and River Stura are defined (Salata et al., 2020). As much as the surrounding is full of green areas, the city itself is densely populated by buildings due to urbanization and expansion. The dense number of buildings results in pollution.

Turin was an industrial city before it became commercial. In the 20th century, Turin was occupied by industries and factories mainly the Fiat car factory. This led to economic, population and physical growth. Social unrest and the loss of Greenfield areas were the results of this rapid urbanization and expansion. Huge portions of the city were abandoned by fleeing industry and population loss as the industrial period quickly came to an end. Turin's green spaces were not subject to as much development pressure due to deindustrialization and population decline. The city's early recognition of the need to provide a sustainable approach to land development and expand the city's green spaces can be seen in the 1995 General Masterplan (European green capital, 2022). Figure 28 and 29 are google earth images which show the minimal difference in physical growth of Turin between 1987 and 2021 due to the development of the city in the 16th century.

The Municipality of Turin has made its goal to make Turin a Smart City. Strategies have been implemented throughout the years to find solutions in mitigation of climate change. Turin is one of the cities in Europe moving towards reducing carbon emissions in the atmosphere which aids in mitigating climate change.

Fig. 28 1987 Satellite view of Turin
Retrieved from Google Earth (2022)

Fig. 29 2021 Satellite view of Turin
Retrieved from Google Earth (2022)

1. Climate Analysis

The climate in Turin is mild, with few temperature extremes and regular amounts of precipitation throughout the year. It is situated between 350 and 600 N and S latitude, poleward of the Mediterranean climate region on the western borders of the continents. Marine west coast climates encounter the mid-latitude westerlies and moving frontal cyclones all year long, in contrast to their equatorial neighbors, who are positioned beyond the farthest poleward range of the subtropical anticyclone. Due to the shifting location and intensity of these storm systems, yearly precipitation accumulations fluctuate significantly throughout the year, but they typically fall between 500 and 2500 mm with local totals surpassing 5000 mm when onshore winds strike mountain ranges. Not only is the rainfall abundant, it is reliable and it rains frequently. In many areas it rains more than 150 days a year, but often less. Fog is common in autumn and winter, but thunderstorms are rare. Strong winds can occur in winter. Winter temperatures are generally mild, but summer temperatures are mild (weatherbase.com, 2022). The Köppen climate classification subtype for this climate is Cfa (Dahl et al. 2019).

1.1. Precipitation

Rainfall in Turin is quite abundant throughout the year. It averages to about 1000 mm per year. The wettest season is late spring and autumn while winter has the least rain. The rain in late spring season is mostly due to the afternoon thunderstorms making May the wettest month in the year with an average of 145 mm. The least wet month is December with average rainfall of 45 mm (Climate-Turin, 2022). During the winter, snow falls at least once a year in Turin. Even though snowfall is less, it amounts to 25 mm on average per year (Climate-Turin, 2022).

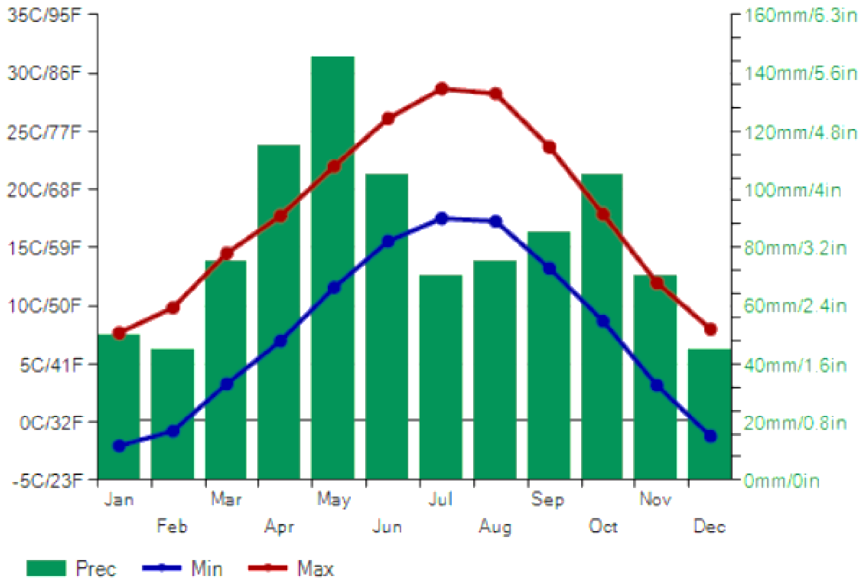


Fig. 30 Average temperature and rainfall of Turin
Retrieved from Climatestotravel.com (2022)

1.2. Temperature and Sun path

The atmospheric temperature in Turin varies with seasons. Summers usually have the highest temperatures with the warmest month being July having an average high temperature of 27.9°C and an average low temperature of 16.9°C. On the other hand, the coldest month is January with an average high temperature of 6.6°C and an average low temperature of -2.5°C (weather-atlas.com, 2022) as shown in fig 30.

Since Turin experiences seasons, summer has the longest days while winter has the shortest. The month with the longest hours of daylight is July with an average of 5 hours and 34 minutes while December has the least hours of daylight averaging 8 hours and 50 minutes. The amount of sunshine varies from daylight. The month with the most sunshine is July having an average of 8.4 hours and the month with the least sunshine is December with an average of 3.5 hours (weather-atlas.com, 2022).

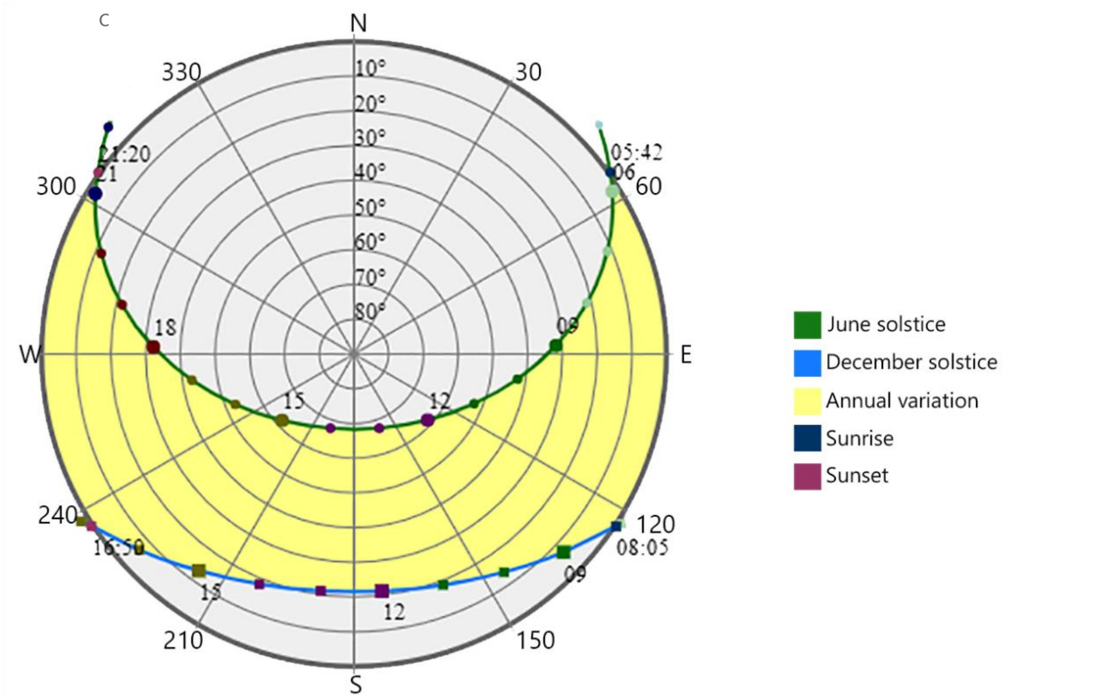


Fig. 31 Stereographic sun path diagram of Turin
Retrieved from gaisma.com (2022)

2. Air Pollution

Turin is among one of many urban cities which faces air pollution. The main sources of pollution are in relation to human activities and industries. The transport sector is the main source of pollution according to the municipality of Turin due to the mobility of the public. Secondary sources include combustion, industrial processes and waste treatment (Pessagno, 2021). The main pollutants are PM2.5, PM10, NO_2, O_3 and SO_2. These pollutants are present in the atmosphere having the particulate matter in abundance which can be a health risk for occupants of the city in the long run. Green covering can potentially reduce the presence of PM in the air (Pessagno, 2021)

3. Green areas in Turin

Due to its extensive green stretch, Turin is regarded as a privileged urban environment. The city is actually one of the greenest urban areas in Italy, and the current vegetation is a blend of spontaneous growth and a variety of human interventions over time. After the

Duchy of Savoy was transferred to the city in 1559, which ordered the requalification and extension of the new capital, various green spaces were created over the years to serve as royal gardens as well as hunting paths (Pessagno, 2021).

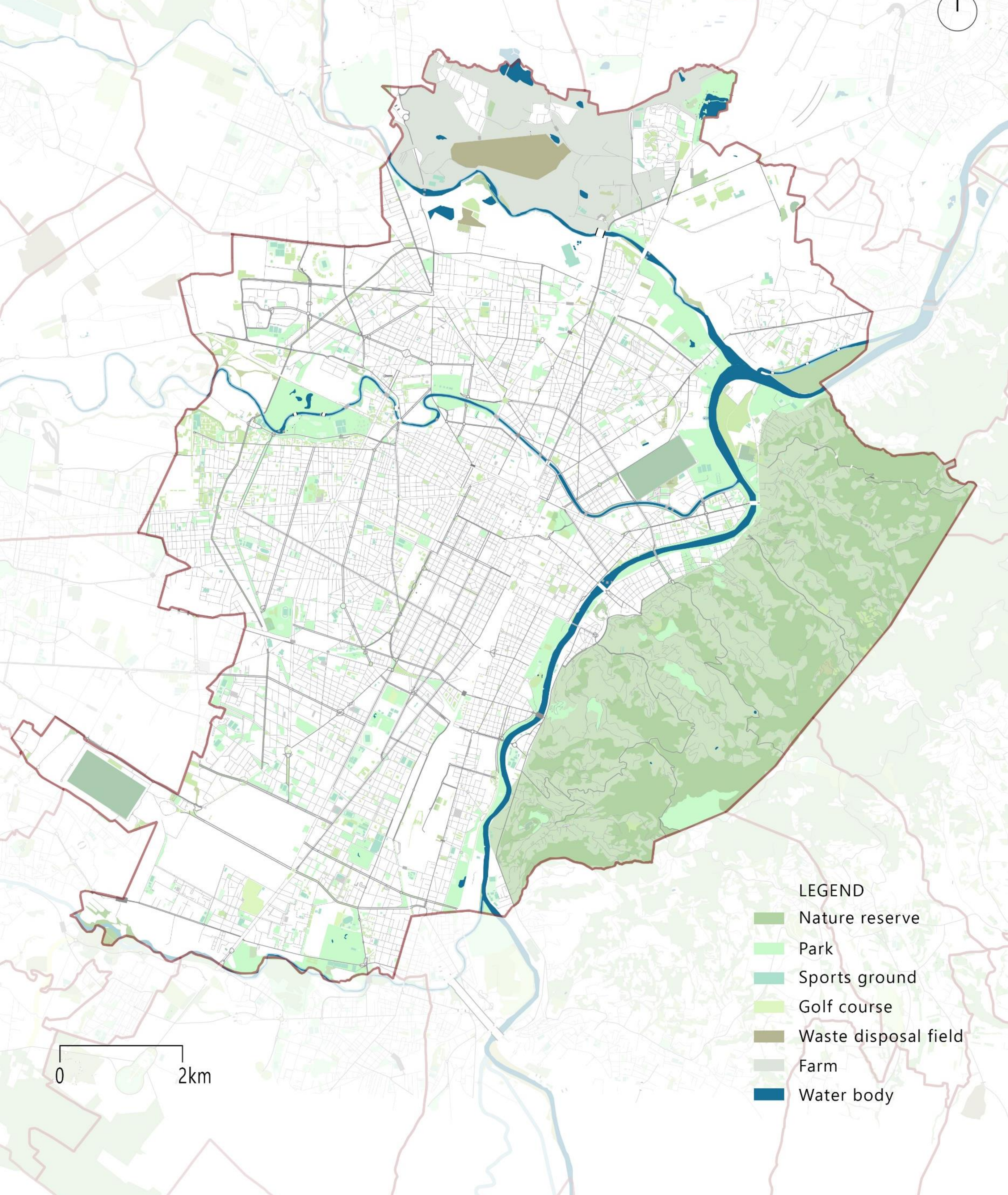
In the early 19th century, more green interventions were introduced by Napoleon. Tree lines along the roads and streets were implemented around the city. At this point, the concept of public spaces and parks and gardens was established in the city of Turin. Among the first public park to be realized is the Parco Del Valentino.

According to the Comune di Torino (2018), the entire area of publicly maintained green spaces in the municipal area now totals 19.569 km^2, or 16.5 percent of the total area. Gardens, cemeteries, sports fields, parks, street tree lines, agricultural regions, and natural formations near the Alps and rivers make up today's distribution of green spaces. Figure 32 shows the generous amount of green spaces dispersed across the city. On the surface, they appear to be distributed very regularly. In addition, there is more greenery close to the rivers and the city borders.

4. Green Roofs in Turin

Turin is not new to green roofs. In order to mitigate climate change, Turin imposes the construction of green roofs. Due to the effects of Urbanization and pollution, the municipality of Turin has regulations on green roofs and their construction especially on newly realized buildings. Turin has a good number of buildings with green roofs as shown in figure 33. The oldest one is the environmental Park which was constructed in 1999 with one of the aims being to reduce the effects of climate change. A maximum of 60,000 m^2 of Turin's rooftops are green, of which 20,000 m^2 are covered by the Environmental Park, composing more than 30% of the entire city's green roof density (Pessagno, 2021). The green roof case study in this thesis is the project called 25 Verde in Turin.

Fig. 32 Spatial distribution of Urban Green Areas in Turin
Adapted by author based on Google maps (2022) and Open Street maps (2022)



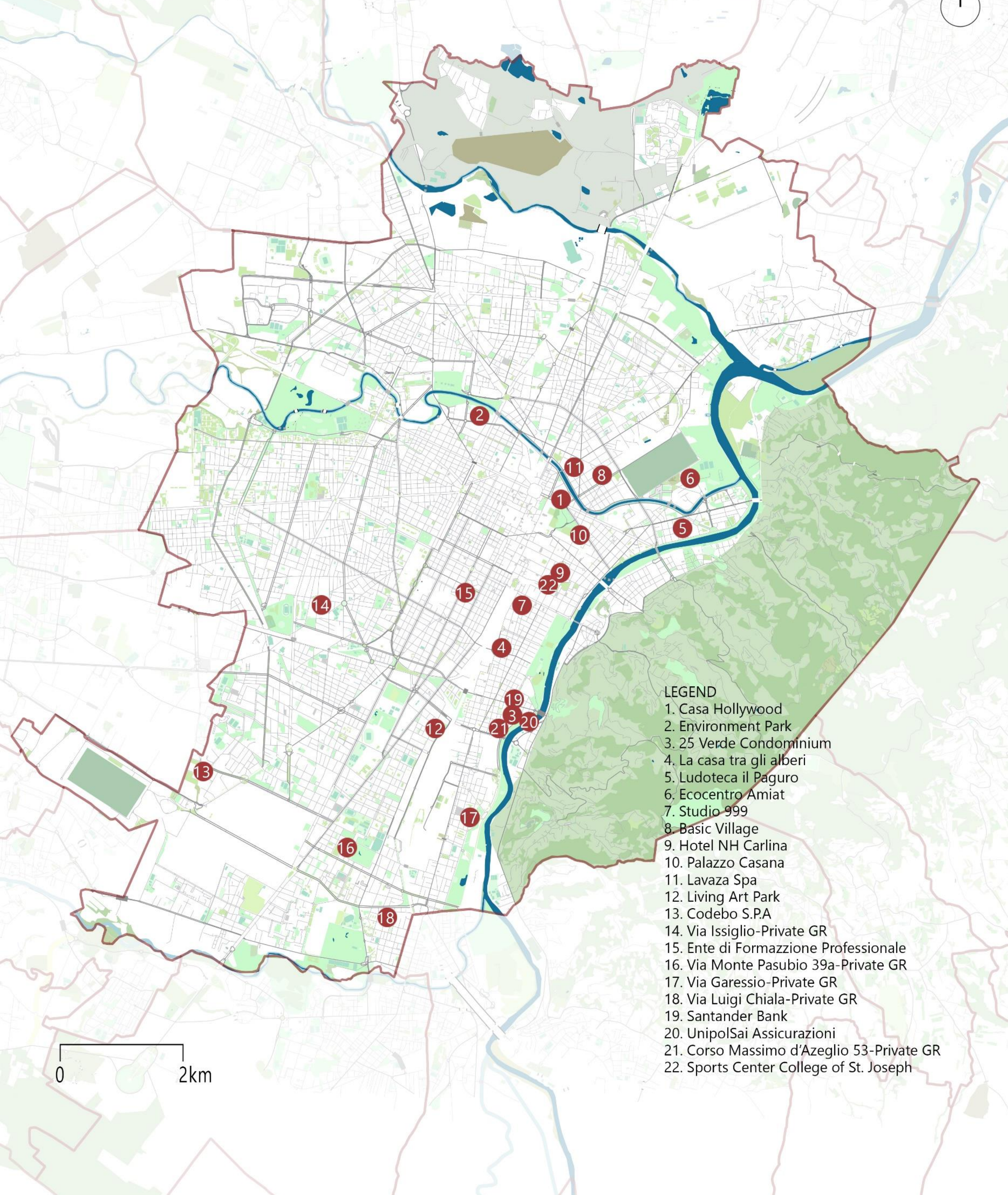


Fig. 33 localization of Green Roofs in Turin
Adapted by author based on Google maps (2022), ZinCo (2022), Geoportale Torino (2022) and Pessagno Echenique, V. K. (2021)

5. 25 Verde, Turin.

The project is located in the midst of the center of Turin. It is known as a unique project covered with green facades and roof. The 25 Verde is a residential building of total area of 7000 m^2 with 4000 m^2 of green roofs and terraces designed by architect Luciano Pia and landscape architecture company, Lineeverdi in Turin. The construction was completed in the year 2012. The building is a residence complex comprising of 63 units all uniquely designed with irregular shaped terraces. The top most floor has 9 apartments which have access to their private green roofs through spiral staircases (Lineeverdi, 2022).

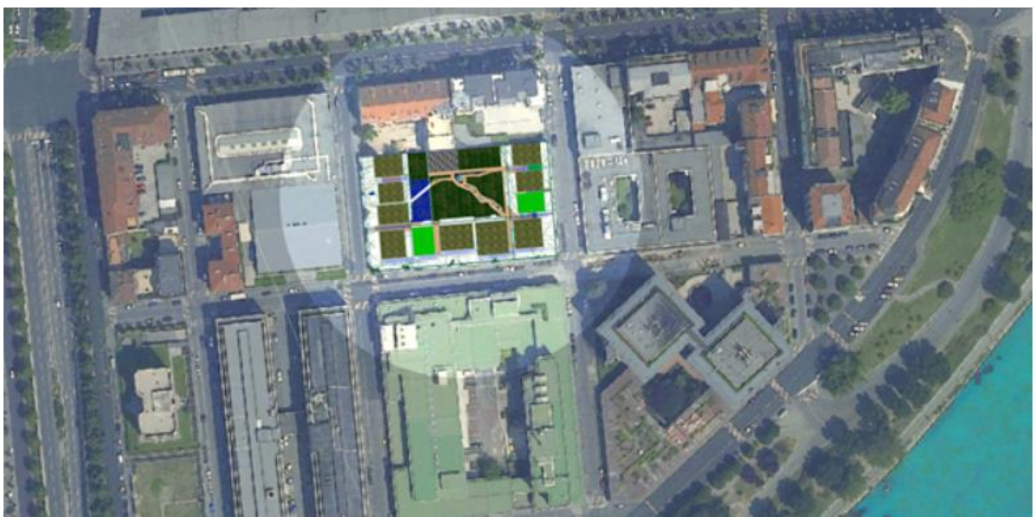


Fig. 34 Site plan of 25 Verde
Retrieved from (lucianopia.it, 2022)

The main objectives of this project were to have maximum energy efficiency and reduce urban heat island effect. To enable the building to cope with heatwaves, and increased temperature in general, two measures have been integrated in the design of 25 Verde: thermal insulation and energy efficiency. To achieve both several combined solutions have been adopted. The structure of the building is characterized by: (climate-adapt, 2022)

- high thermal mass that holds through the 35 cm thick solid floor slabs;
- exterior increased thickness brick walls;

- continuous exterior thermal insulation and ventilated façade;
- passive solar protection through louvers and deciduous plants;
- wide glass surfaces for winter solar gain and for improved interior natural lighting;
- Green roof, which includes a thick layer of soil.

5.1. Vegetation cover

The type of rooftop vegetation is intensive. In the interview conducted with the team of Lineeverdi, Stefania and Chiara explained that a traditional green roof system was used, placing a second concrete screed above the waterproofing sheath (with the right slopes and many drains on the perimeter for draining the water), which protects the sheath. Also, other layers placed on the roof were; one anti-root fabric, a draining layer of volcanic lapillus of height min 10-20 cm; a separation layer and then a lightened substrate specific for vegetation of height about 40 cm (Lineeverdi, 2022).

The vegetation includes grasses, trees, orchards, flowers and fruit trees. Due to the soil's high thermal inertia and ability to filter and absorb rainwater, which reduces the need for irrigation water and delays the flow of rainwater to the ground, the soil also acts as a thermal insulator. The green roof is private property managed by residents of the top floor (climate-adapt, 2022).

Fig. 35 Green roof of 25 Verde.
Retrieved from (due.to.it, 2022)

Fig. 36 green roof plan and section of 25 Verde.
Retrieved from (designboom.com, 2022)

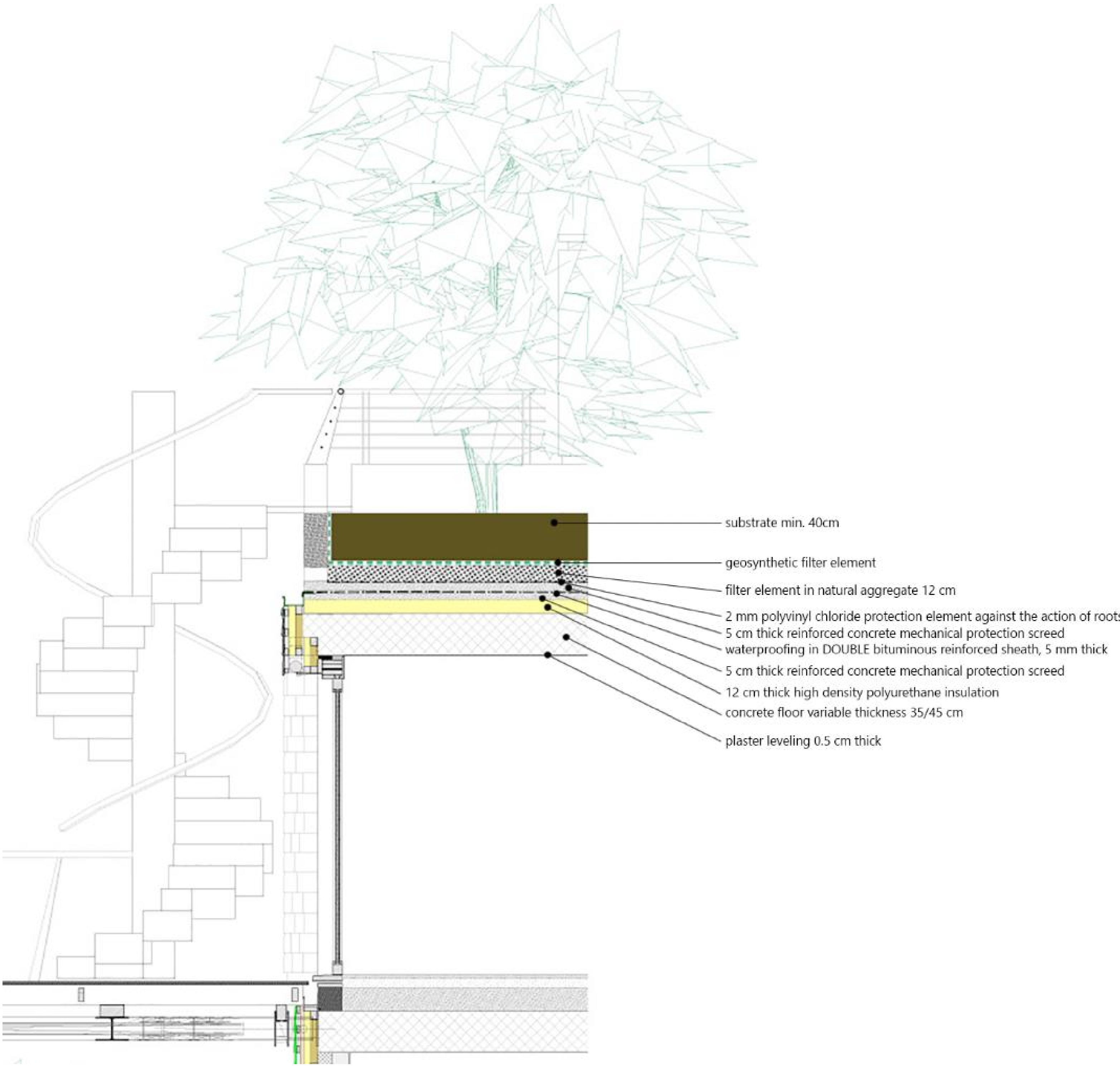


Fig. 37 green roof structural section of 25 Verde. Adapted by author from Luciano Pia (2022) and designboom.com (2022)

During the construction of the green roof the challenge was handling the materials and plants since they needed to be handled with care and delicately. The assembling of the green roof was done on site layer by layer. The trees were however brought in by a crane and planted on the roof. The choice of vegetation on the roof was given to the owners of the apartments with green roofs. Some chose to plant vegetables and rose gardens while others chose to have grasses and herbaceous trees (Lineeverdi, 2022). Either way the green roofs provide an aesthetic view and a calming social space for relaxation. The maintenance of the green roof is taken care of by the owners of the apartments.

Fig. 38 25 Verde roof before construction of green roof.
Retrieved from Lineeverdi.com (2022)

Fig. 39 Installation of substrate layer on rooftop of 25 Verde.
Retrieved from Lineeverdi.com (2022)

Fig. 40 Installation of substrate layer on rooftop of 25 Verde.
Retrieved from Lineeverdi.com (2022)

Fig. 41 Installation of substrate layer on rooftop of 25 Verde.
Retrieved from Lineeverdi.com (2022)

Fig. 42 Intensive green roof installed on rooftop of 25 Verde with seating area.
Retrieved from Lineeverdi.com (2022)

Fig. 43 Fig. 42 Intensive green roof installed on rooftop of 25 Verde.
Retrieved from Lineeverdi.com (2022)

5.3. ISTANBUL

Istanbul is one of the fastest growing metropolitan city in the world and the only city shared by two continents; Europe and Asia. With an area of 5,343 km^2 (Akin, A et al., 2015), Istanbul is the largest inhabited city in Turkey with a population of 15.5 million as of 2019 (TUIK, 2022) where 64.4% of inhabitants reside in the European side and 35.6% in the Asian side (TUIK, 2022). It is the hub of social, economic and historical importance making it the only city in Turkey with the highest population increase rate. Istanbul is located in the north-west region of Turkey bordering the Black Sea and Sea of Marmara (Figure 44).

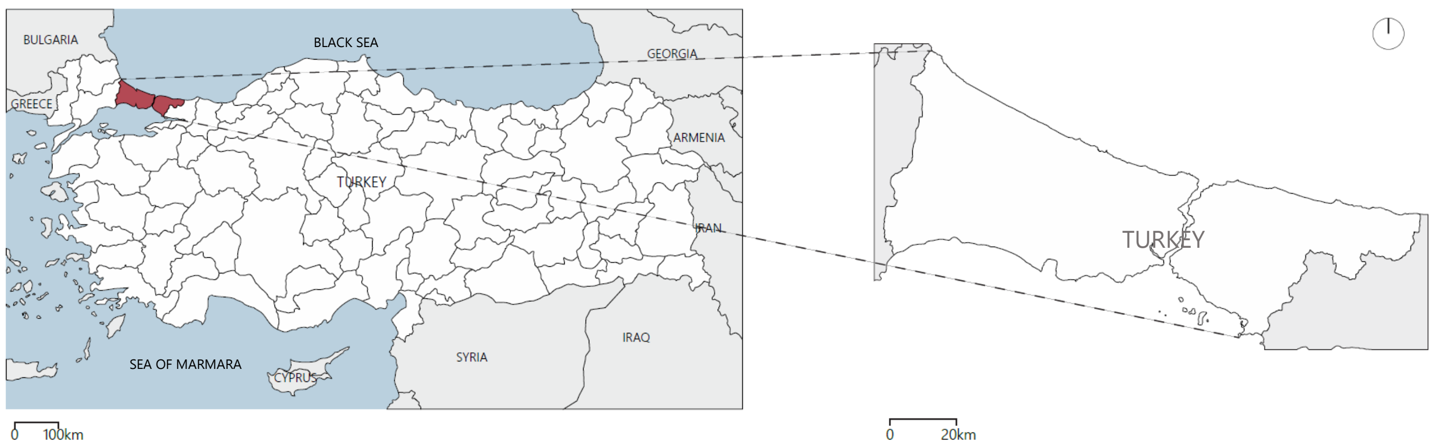


Fig. 44 Location of Istanbul, Turkey
Adapted by author from (d-maps.com, 2022)

The urban settlements in Istanbul are seen on the south while the north of Istanbul is mostly covered in forests. Talking about urban settlements, Istanbul has experienced a drastic increase in urban development in the 20^{th} century which was as a result of industrialization that occurred after 1950 and the migration of people due to the industrial development (Şahin, C. 2022). The land area of Istanbul expanded rapidly, all the while under the control of factors affecting spatial development, until it reached the current city limits. The city, which began on the European continent, eventually spread to Asia. Today's Istanbul is a city that connects these two continents. The bridges built across the

Bosphorus Strait are key components in formalizing this union (Şahin, C. 2022). The expansion of the urban fabric is seen in figure 45 showing the difference in development in the years; 1972, 1986 and 2013. The most significant stage of spatial development in Istanbul was experienced in the second half of the 20th century as seen in figure 45.

The geographical features of the land of Istanbul influenced the physical development of the city. Istanbul was formed on a peninsula lying from east to west, with the Golden Horn to the north, the Bosphorus to the east and the Marmara Sea to the south. Due to this, the city grew keeping in mind the shape of the peninsula. Alternatively, areas suitable for settlement, transportation routes, industrialization, residential areas, administrative structure changes, and populations were also determining factors in the city's spatial development (Şahin, C. 2022).

Evidently, the amount of natural green spaces in the city reduced significantly. The industrialization and urban development of the city is responsible for the reduced green spaces in Istanbul. With a populous and congested city like Istanbul, vegetation is necessary to counter the effects of climate change and reduce pollution. A strategy is to increase the application of green roofs in the city.

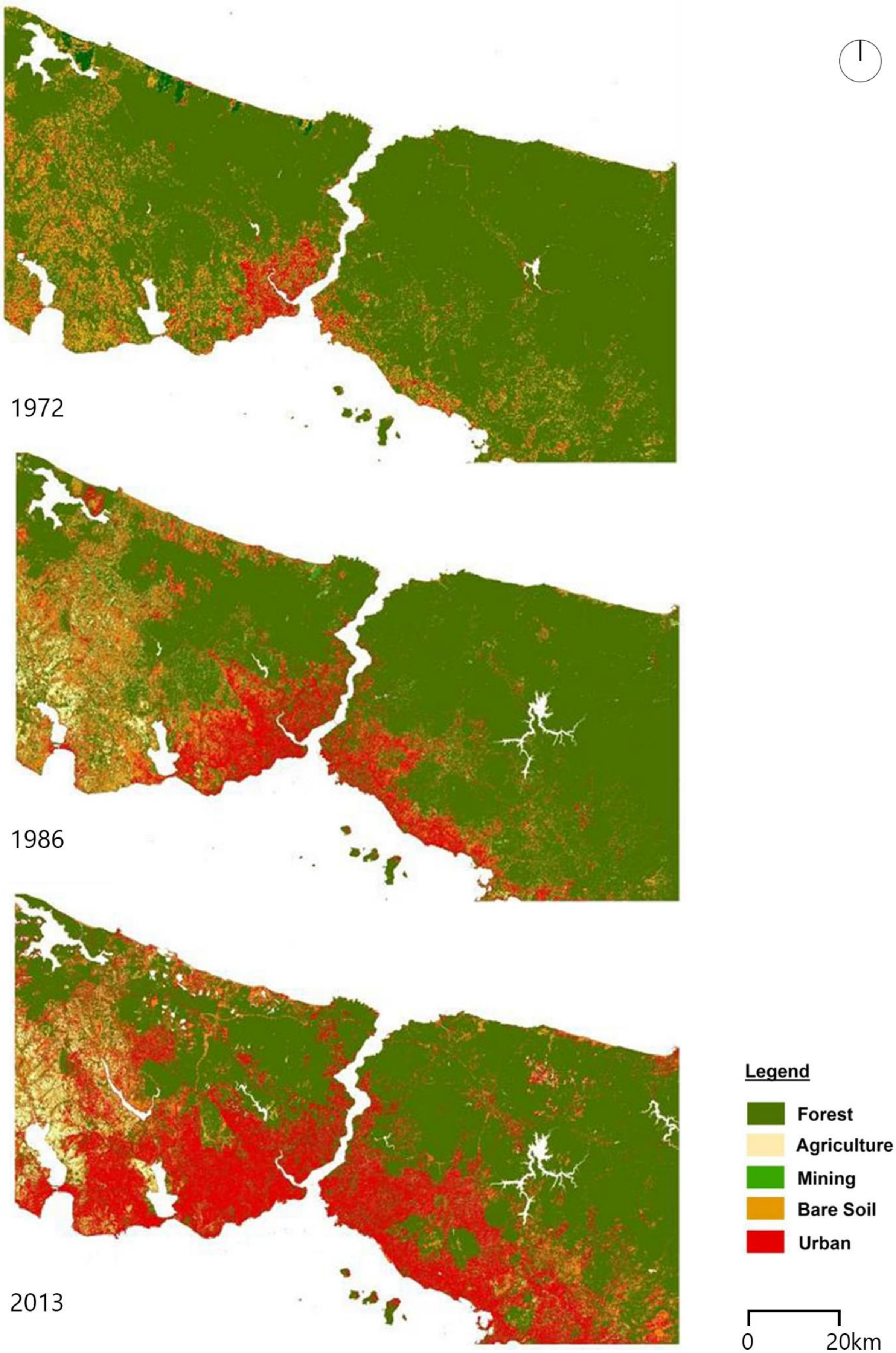


Fig. 45 Land cover map of Istanbul, Turkey
Adapted by author from (Akın, A. et al., 2015)

1. Climate analysis

Istanbul lies in the northern hemisphere. Under the Köppen classification, Istanbul has a borderline Mediterranean climate Köppen Csa, humid subtropical climate Köppen Cfa and oceanic climate Köppen Cfb (Kottek et al. 2006). Depending on location, it has mild to hot summers with a mean temperature rising at 20 °C to 25 °C in August and cool winters with regular precipitation. Depending on the direction of the wind, spring and fall are often moderate seasons. The Sea of Marmara to the south and the Black Sea to the north both have a significant impact on the weather in Istanbul (Kottek et al. 2006).

Istanbul typically receives some precipitation from both Western European and Mediterranean systems because it is only marginally rain shadowed from Mediterranean storms and is otherwise surrounded by water. As a result, precipitation occurs often during the winter months; in January, 20 days of precipitation on average, 17 days when using a 0.1 mm criterion, and 12 days when using a 1.0 mm threshold (Infoclimate, 2022). The occurrence of precipitation is constant throughout the year, with winter accounting for 38% of total precipitation, followed by spring (18%), summer (13%), and autumn (31%). The driest time of year is in the summer, however unlike a real Mediterranean climate, there is no dry time of year. The average number of rainy days in the city is 131, while some areas may have up to 152 (weather statistics for Istanbul, 2022).

As in practically every other region of the world, climate change is making Istanbul more susceptible to heatwaves, droughts, storms, and flooding (ŞEN, 2022). Additionally, Istanbul's urban heat island has been accelerating the consequences of climate change due to the city's size and rapid growth. It is highly likely that these two variables are what caused metropolitan Istanbul's climate to change from a warm-summer climate to a hot-summer climate according to Koppen classification. If current trends hold, sea level rise is likely to have an impact on municipal infrastructure with a risk of flooding. Green spaces

Xeriscaping has been proposed, and a climate change action plan for Istanbul has been proposed (Istanbul İklim Değişikliği Eylem Planı Hazırlanması Projesi. 2019).

1.1. Precipitation

Rainfall in Istanbul varies throughout the year. The wettest season is winter with December being the month with the most rainfall having an average of 105 mm. The months with the least rainfall are June and July with an average of 25 mm. The total amount of Rainfall averages to 680 mm (Climate-Istanbul, 2022). Snowfall in Istanbul is experienced more than once a year. The period of snowfall is between January and February. The most snowfall occurs in February with an average of 35 millimeters (weatherspark.com, 2022).

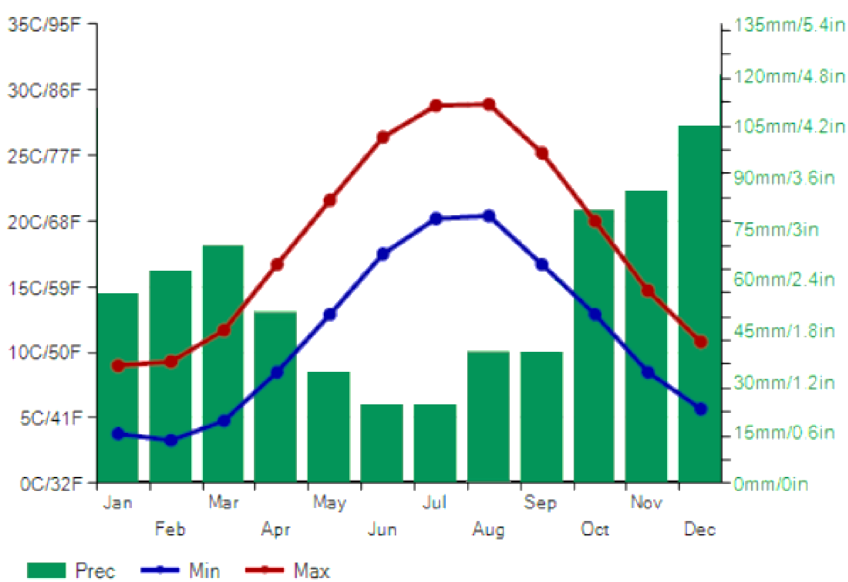


Fig. 46 Average temperature and rainfall of Istanbul
Retrieved from Climatestotravel.com (2022)

1.2. Temperature and Sun Path

Istanbul experiences hot and sunny summers and cold winters. The hottest month of the year is August with an average high temperature of 29.9°C and average low temperature of 21.8°C while the coldest month is January where the average high temperature is 9°C and the average low temperature is 3.3°C (Climate-Istanbul, 2022). The performance of green roofs is also affected by the amount of sunshine. In Istanbul, the month with the most sunshine is July with an average of 11.8 hours and the least sunshine is in December with an average of 4.8 hours. On the other hand, daylight in Istanbul has longer hours. The month with the longest days is June averaging 15.1 hours and the shortest days are in December with average daylight of 9.3 hours (weather-atlas.com, 2022).

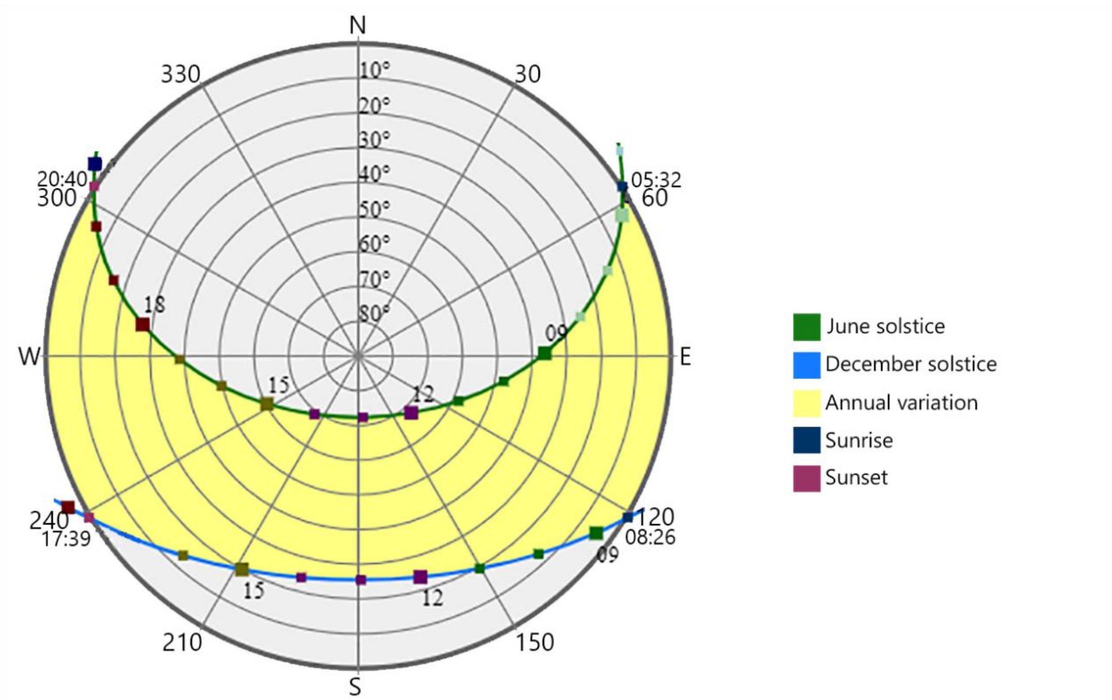


Fig. 47 Stereographic sun path diagram of Istanbul
Retrieved from gaisma.com (2022)

2. Air pollution

With a population of almost 15 million, Istanbul is the largest metropolis in Europe and ranks as the fifteenth largest city in the world. When it comes to pollution, Istanbul's PM2.5 measurements in 2019 were 19.7 μg/m^3, placing it in the 'moderate' category for air pollution, according to the Environment protection agency (IQAir, 2022). With this designation, Istanbul falls within the middle of this range for the quantity of PM2.5 in the air, with measurements ranging from 12.1 to 35.4 $\mu g/m^3$. This shows that there are some pollution problems in the city. Any readings above the World Health Organization's (WHO) target goal of 0 to $\mu 10\ g/m^3$ indicate that the air may be unsafe to breathe, and with moderate ratings throughout the year, the air quality may pose a risk to those who are sensitive to chemical pollutants, as well as to young children, the elderly, or those with compromised immune systems (IQAir, 2022).

Vehicle emissions are among the primary contributors, with older and out-of-date cars being the worst offenders because they emit far more pollutants than more recent and "greener" versions. In particular, diesel-powered heavy-duty vehicles like lorries, trucks, and buses are to blame for increasing annual average PM2.5 readings. Additional sources include factories and industrial areas that burn coal and other fossil fuels, as well as construction sites. These additional sources can lead to increased airborne levels of tiny particulates like PM2.5 and PM10, which can be harmful to the health of the residents of Istanbul (IQAir, 2022).

The main pollutants are nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) which mainly come from vehicles. Volatile organic compounds (VOCs) can be released as well through vehicles especially those that run on diesel. Formaldehyde, benzene, and methylene chloride are a few VOCs that could be present in the air in Istanbul. Carbon monoxide (CO) and polynuclear aromatic hydrocarbons are pollutants released during combustion of wood (IQAir, 2022). To reduce the levels of pollution, one of the strategy that can be used in Istanbul is the implementation of green roofs.

3. Green areas in Istanbul

Istanbul has a variety of green areas throughout the city. There are twenty parks centralized in the city centre, but only nine of them are public parks and gardens (Högberg, 2020). The green area ratio per person in the city of Istanbul is only 6.4 square meters, according to Istanbul Metropolitan Municipality. The Istanbul branch president for the Ministry of public works and Settlement Erhan Demirdizen expresses the importance of green areas in terms of aesthetics, preventing air pollution, softening the climate and creating a habitable environment (Högberg, 2020). Demirdizen also remarked that in order to meet international standards, there should be at least one park or other green space within 700 to 800 meters of any location. He also emphasized the necessity to prevent green spaces from turning into one giant block of concrete (Jalali, 2002).

Turkey confronts significant difficulties in enhancing the quality of life in urban areas, where urban green spaces have emerged to enhance the quality by purifying the air from pollutants, reducing noise, heat waves, protecting the city's groundwater from contamination, and preventing soil erosion. Turkey desperately needs green infrastructure, so while it is undoubtedly a challenging endeavor, it is also a crucial one. (Jalali 2002).

Istanbul has worked hard over many years to preserve its green spaces and transform into a greener city, which is definitely a tremendous chance for the city's appeal to new investors, residents, and establishment on the global stage. But even though providing everyone with access to green space is a sub-target of Istanbul's regional development plan, doing so is challenging because the state's interest on economic growth and practical infrastructure development has led to a sharp decline in the size and number of green spaces (Baycan-Levent 2003).

4. Green Roofs in Istanbul

Istanbul is not new to green roofs. Following examples from Germany and other parts of Europe, Istanbul has also initiated the application of green roofs on buildings to mitigate adverse effects of climate change since vegetated roofs come with a lot of benefits. Istanbul is among the most densely populated cities in the world creating one of the fastest growing urban fabric. Recently, the municipality of Istanbul has implemented laws on construction and implementation of green roofs as of 2018. The new zoning regulations entails a new policy for the implementation of green roofs. All private and public buildings to be newly built with an area of more than 60 thousand meters squared are required to implement green roofs in order to provide thermal and noise insulation and for other environmental benefits (Dergisi, 2018).

The most common building type with green roofs in Istanbul are shopping Malls followed by hotels. It is rare to see residential buildings with green roofs. There are about 22 buildings with vegetated roofs in Istanbul according to the author’s research. Most of them are concentrated in the central part of Istanbul which is mostly a commercial area while a few scattered on the European and Asian side of the city. Figure 49 shows the localization of green roofs in the city. The green roof case study in this paper is the Meydan Retail complex and multiplex located in Urmaniye, Istanbul.

Fig. 48 Urban Green areas in Istanbul
Adapted by author based on Google maps (2022), Open Street Maps (2022)

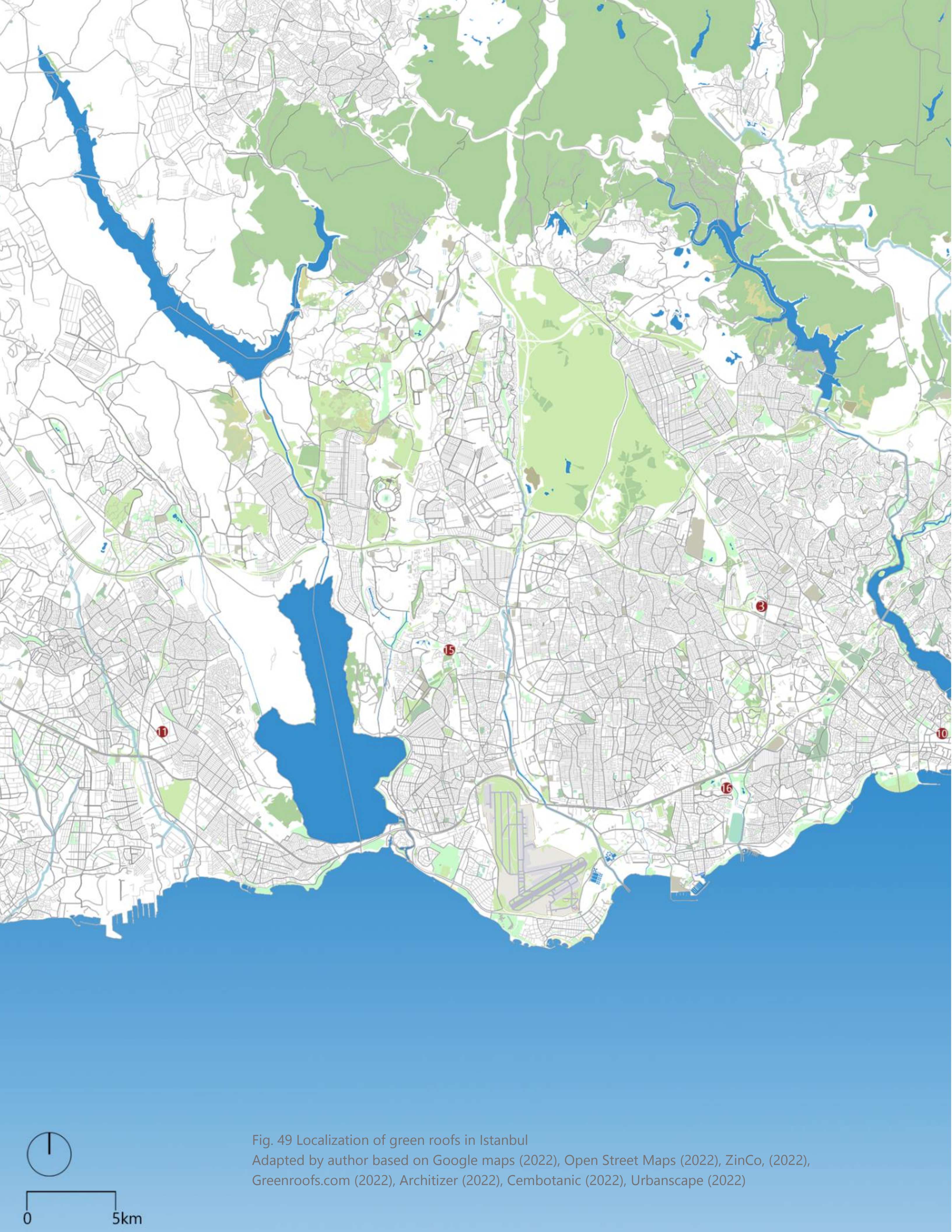
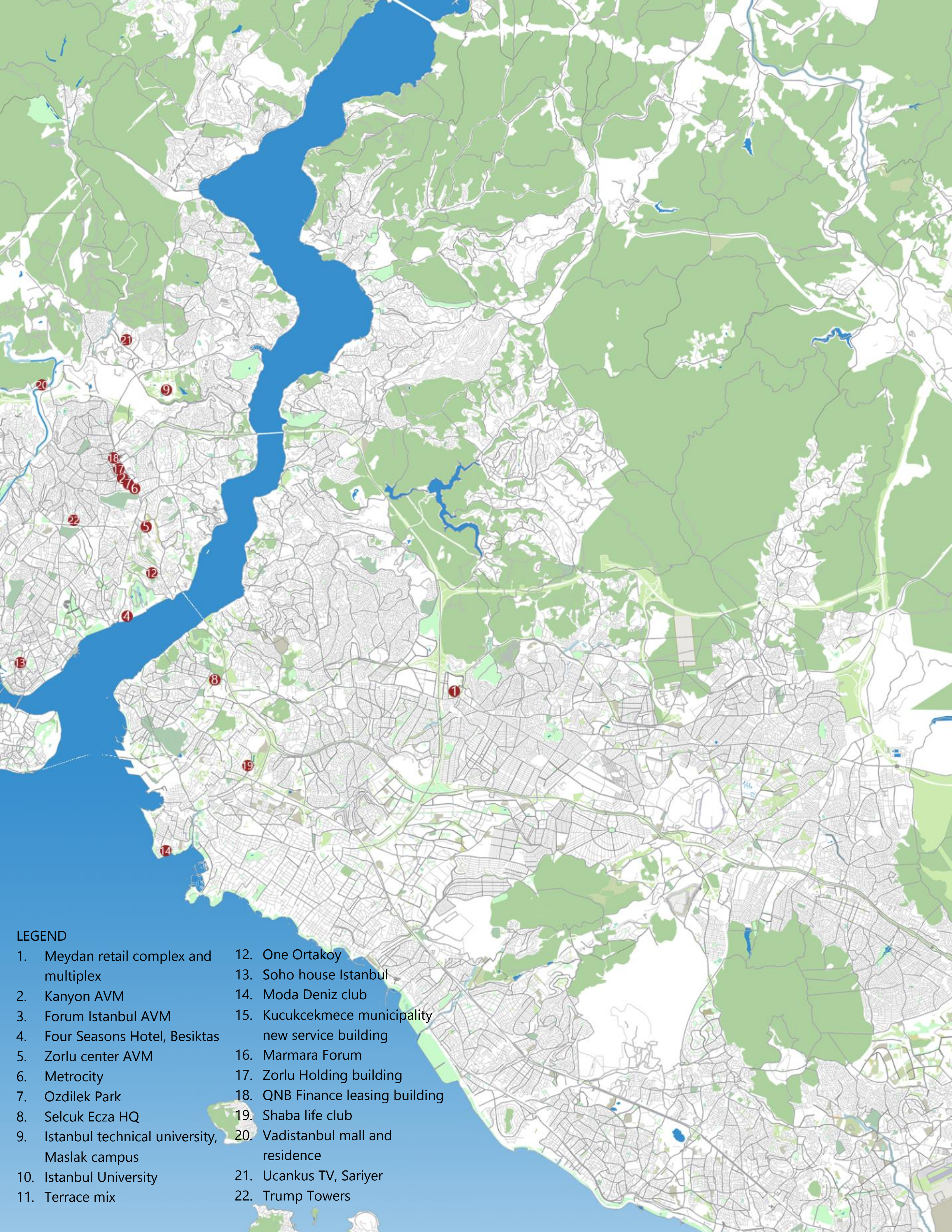


Fig. 49 Localization of green roofs in Istanbul
Adapted by author based on Google maps (2022), Open Street Maps (2022), ZinCo, (2022), Greenroofs.com (2022), Architizer (2022), Cembotanic (2022), Urbanscape (2022)


LEGEND
1. Meydan retail complex and multiplex
2. Kanyon AVM
3. Forum Istanbul AVM
4. Four Seasons Hotel, Besiktas
5. Zorlu center AVM
6. Metrocity
7. Ozdilek Park
8. Selcuk Ecza HQ
9. Istanbul technical university, Maslak campus
10. Istanbul University
11. Terrace mix
12. One Ortakoy
13. Soho house Istanbul
14. Moda Deniz club
15. Kucukcekmece municipality new service building
16. Marmara Forum
17. Zorlu Holding building
18. QNB Finance leasing building
19. Shaba life club
20. Vadistanbul mall and residence
21. Ucankus TV, Sariyer
22. Trump Towers

Meydan Retail Complex and Multiplex

This project is located in the Asian side of Istanbul. It was designed by Foreign Office Architects in London and developed by Turgut Alton Architects in Istanbul. Meydan Retail Complex and Multiplex was inaugurated in August 2007 in the neighborhood of Ümraniye with a total area of 120,000 m^2 and 30,000 m^2 of green roofs (Turgut Alton Architects, 2022). According to the client, the new shopping center "Meydan," which is Turkish for "marketplace" or "meeting point," is an entirely new idea for shopping centers. Its open architecture is meant to entice people to shop and move around.

This idea is novel in that it organizes a total of 50 stores, eateries, and cafes into five "theme worlds" that are centered on the main plaza. As a result, rather than being dispersed throughout a 70,000 m^2 massive building complex, visitors will find the shops and leisure areas united and easily accessible via stairs and ramps.

The shopping center "Meydan" has never had the peculiar architectural and unique technologies together before. The Meydan Shopping Center is an unrivaled example of an innovative retail development thanks to its creation as natural meadows and partially accessible roof areas, smooth transitions between the various building structures, and one of the largest geothermal plants in Europe with more than 200 drillings up to 150 m deep, which enables the climate-friendly heating and cooling of the Meydan Shopping Center (ZinCo, 2022).

Fig. 50 Birds eye view of Meydan shopping center
Retrieved from (Turgut Altun Architects, 2022)

Fig. 51 Site plan of Meydan shopping center
Retrieved from (Archdaily, 2022)

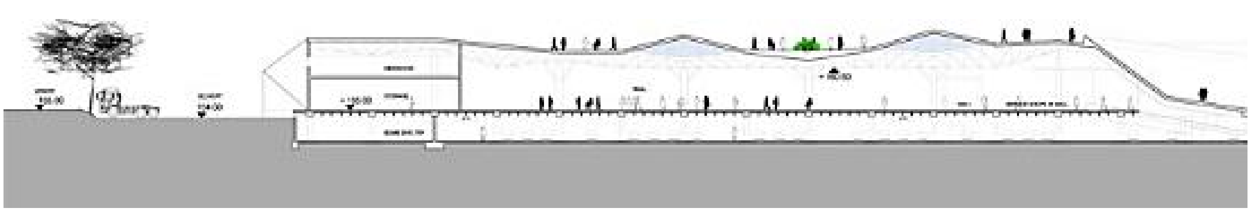


Fig. 52 Part of the section of Meydan Shopping center
showing the sloped green roof
Retrieved from (Archdaily, 2022)

Vegetation cover

The project consists of both extensive and intensive green roofs where part of it is accessible. The vegetation includes meadows, flower plantations, grasses, bushes and shrubs making it a green oasis. It was particularly difficult to grow the natural vegetation that the architects had in mind on the folded and even extremely steeply slanted roof surfaces. The system maker ZinCo used four different green roof systems due to the range of roof circumstances and usages – 16,000 m^2 flat roof not accessible, 1,250 m^2 flat roof accessible, 11,900 m^2 sloped roof up to about 25° pitch, and 1500 m^2 steep pitched roof up to more than 35°. The installation was done by ZinCo's Turkish partner Onduline Avrasya AS from March to August of 2007.

In order to start installing the green roof as soon as the necessary shear barriers were installed in the steep roof areas, the roof construction, which was made of trapezoidal sheets with thermal insulation made of expanded polystyrene foam, was waterproofed with a root-resistant, single-layer membrane that also came from a German manufacturer (Rhepanol of FDT FlachdachTechnologie GmbH & Co. KG). (ZinCo, 2022).

Fig. 53 Meydan shopping center before construction of green roof (ZinCo, 2022)

Fig. 54 Meydan shopping center after construction of green roof (ZinCo, 2022)

Fig. 54 layering of substrate during construction of green roof
Retrieved from (ZinCo, 2022)

Fig. 55 installation of ZinCo-Georaster®-elements for reinforcing the sloped green roof
Retrieved from (ZinCo, 2022)

Fig. 56 Flourished green roof of Meydan Shopping Center
Retrieved from (ZinCo, 2022)

Fig. 57 Accessible part of the green roof with garden furniture
Retrieved from (ZinCo, 2022)

CHAPTER 4

DISCUSSIONS

4. DISCUSSIONS

This chapter discusses the in-depth analysis of the above case studies. It portrays the general comparison of green roof implementation in the three different cities in terms of urbanization, green areas, climate and air pollution, social perception, cost, energy efficiency and government policies or regulations. It also gives a comparison on the specific case studies in the three cities expressed in chapter 3.

4.1. Urbanization

It is not a secret that urbanization has affected every city in the world. The effects of urbanization has led to the loss of green areas in many cities. For Istanbul and Nairobi, the rapid urbanization was evident in the 20^{th} century as shown in the maps in chapter 3. However, for Turin, the development of the city took place in 1500s until 1800s (European green capital, 2022) and has maintained its physical area. The effects of urbanization have affected all the three cities. The main effect is climate change which can be contributed by lack of green spaces. Nevertheless, Turin has been invested in becoming a green smart city. The 1995 general masterplan of Turin showed the need for green spaces in the city. The urban city development plan has used a skilled public-private partnership approach to designate vast tracts of formerly industrial land for green and mixed-use development, totaling over 600 hectares, with 400 ha now green areas (European green capital, 2022).

4.2. Green area per capita

According to World Health Organization, the minimum surface of green area per inhabitant in a city should be at least 9 m^2 while the ideal urban green space per person should be higher. Some researches state that the ideal value of green area per capita should be 50 m^2 (Bell, et al., 2018; Cirella, Russo, 2018). There are more regulations on the accessibility and space quality of the green spaces in addition to the area per inhabitant. (UCL Institute of Health Equity, 2014; WHO, 2016).

- The Accessible Natural Greenspace Standard -ANGSt- This standard states that there should be a 300 m walking distance which is a 5 minutes walk, from the residence to the green space (Mathey, Rink, 2010) this green space should be at least of 20000 m^2 (UCL Institute of Health Equity, 2014).
- The Bristol Council created guidelines for accessible green spaces that recommend a 400 m or nine-minute walking distance to the closest green space. (UCL Institute of Health Equity, 2014).
- The European Common Indicator for Open Spaces, which does not directly refer to green spaces but is based on comparable measures, suggests a 300 meter walk or a 15 minute walk to a 5000 m^2 area. The Environmental European Agency and the Istituto Nazionale di Statistiche Italiano are the organizations behind the implementation of this regulation (Ambiente Italia Research Institute, 2003).

In Turin, the amount of green space per resident is 21.93 m^2 excluding agricultural areas, (Verde Pubblico. 2022). In a broad and general sense, this value complies with the WHO's suggested indicator. The greening per capita in Istanbul is 6.4 m^2 (Högberg, 2020) for a population of over 15 million people, which is less than the regulation for green areas per inhabitant as per WHO. The same goes for Nairobi since the greening per inhabitant is less than 1 m^2 (Ngarachu & Ng'weno, 2015). Therefore there is a great need of increase of green spaces in the cities.

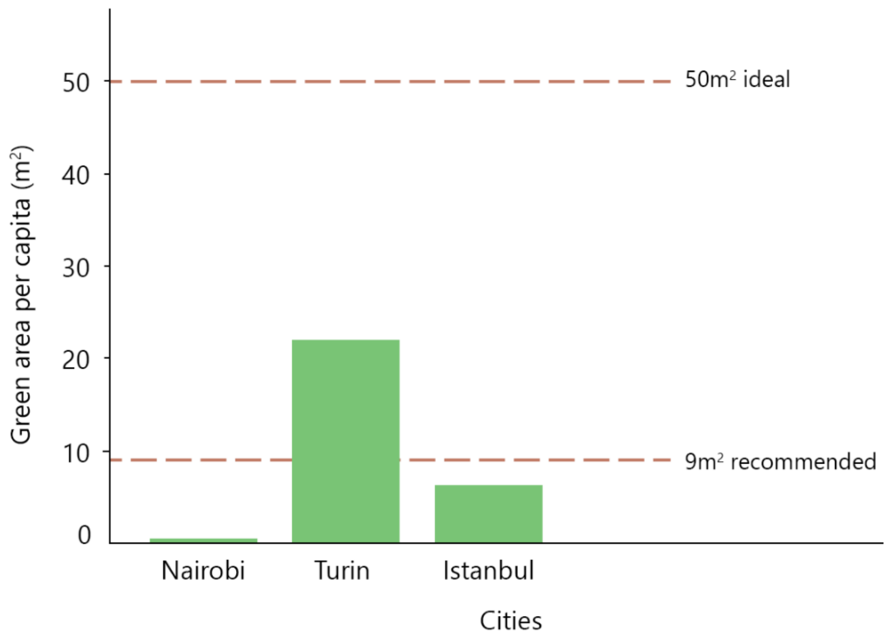


Fig. 58 Green area per capita
Adapted by author from information from Verde Pubblico. (2022), Högberg, (2020) and Ngarachu & Ng'weno, (2015)

4.3. Social perception of green roofs

It is important for the urban population to know about the implementation and benefits of green roofs. In the interview with Andrew from Pharos architects Nairobi, he reported that people of Nairobi are not aware about the concept of green roofs since they are few in number and the existing ones reside in the upper class areas. A study by Kimote (2020) shows that the general public of Nairobi did not know about green roofs and its benefits and when explained about it, majority were afraid of the costs that come with the construction and maintenance of green roofs. This proves there is lack of knowledge about vegetated roofs in Nairobi.

In another interview with Lineeverdi, the company which constructed the green roof of 25 Verde in Turin, they mentioned that at the time of construction which is in 2007, not many people were aware of the concept and would have trust issues and fear of construction and maintenance costs. However the same cannot be said currently. The public is starting to know more about green roofs and the increased number of buildings with green roofs in the city of Turin proves that the general public of Turin have an understanding of the concept of green roofs and their benefits.

As for Istanbul, a study conducted by Tuba Sari Haksever and Ilkim Markoc (2020) on the social perception of green roofs in Istanbul, suggests that the public is aware of the existence and implementation of green roofs as well as multiple benefits they provide. However, not many were educated on the cost and maintenance of the vegetated roof. The study was conducted based on the existing green roof of a shopping complex in Islanbul called Zorlu center.

4.4. Climatic context and Air Pollution

The climate in the three cities varies. As Turin and Istanbul experience all 4 seasons, Nairobi experiences wet and dry periods with a sub-tropical climate throughout the year (Kimote, 2020). The choice of vegetation largely depends on the climatic context on the geographical area. Rainfall, relative humidity, temperature and sun path are essential factors in the performance of a green roof. The process of watering plants affects how they take up nutrients and carbohydrates as well as their ability to photosynthesize. Water quantity and frequency considerations are just as important for this action as water quality considerations. Storm water possesses both qualities since it is soft water good for the plants and falls in good amounts. Precipitation in Nairobi, Turin and Istanbul is relatively abundant throughout the year which is beneficial for the green roofs. The use of sedums as vegetation on green roofs has been proven to be ideal since it does not require a lot of water and maintenance for growth giving less need for external irrigation. In cases where intensive green roofs are installed, irrigation systems are installed in addition to the rainfall since the plants require more water to flourish.

Atmospheric temperatures and light intensity also affect the growth performance of plants. The essential determinant in transpiration and photosynthetic processes is the amount of solar radiation, whereas temperature is mostly related to transpiration but may also limit photosynthesis if low temperatures are paired with other factors. For instance, if low temperatures happen during brief growing seasons (Cascone et al., 2018; Tooley and Sheail, 2019). Therefore, increased solar radiation improves the above mentioned vegetative processes. Insulation helps to warm the atmosphere, and increased transpirational cooling rates result from a rise in air temperature. The vapor pressure difference between the plant and the air rises when the heat is increased (Pessagno, 2021). The phenomenon is also accelerated by temperature, which causes greater stomata openings. As a result, vegetative roofing performs better on sunny summer days than on sunny winter ones because of the heat and increased sun radiation intake during that time (Cascone et al. 2018). The summer period in Istanbul and Turin are better for the blooming of vegetated roofs at a faster rate compared to the winters due to the reduced temperatures. However, in Nairobi the growth rate of rooftop vegetation is similar throughout the year because of less variation in temperature and sunshine hours during the course of the year.

When it comes to pollution, all three cities are affected by it which causes health problems to the residents. Vegetation can eliminate pollutants in the atmosphere however if levels are excessive, the plants can be at risk too. They can directly absorb pollutants from the air through their stomata or from the moisture in the soil through their roots. The implementation of green roofs can improve the air quality of urban cities creating a livable and safe environment for the inhabitants.

4.5. Government Policies and Regulations.

Green roofs implementation has prompted many countries to come up with regulations and construction policies. Nairobi city however currently does not have any kind of policy or regulation on the construction and implementation of a green roof. Andrew of Pharos architects mentioned that during construction of the French embassy, they did not find any Government or municipality guidelines to follow. The construction was based on a conventional green roof system.

Green roofs in Turin are constructed using the Italian standard; UNI 11235:2015 "guidelines for the design, execution, inspection and maintenance of green roofs" (Mutani and Todeschi, 2020). This is the main policy for the construction of green roofs in Turin. Apart from that, Turin has

In Istanbul, there were no specific standards for the construction of green roofs until 2018. Green roof systems are generally used to be imported readily from other countries. This is one of the reasons as to why there is a limited number of green roofs to the number of population in the city (Külekçi, 2017). However, Istanbul zoning regulations changed in May 2018 with the number 30426 and a mandate for green roof implementation was issued (Dergisi, 2018). The mandate states that all private and public buildings newly constructed with an area of more than 60 thousand meters squared are required to apply green roofs in order to provide thermal and noise insulation and for other environmental benefits (Dergisi, 2018).

Apart from the new regulation, Turkey has created certification systems in regards to green roofs and energy.

- In May 2007, ÇEDBİK (Çevre Dostu Yeşil Binalar Derneği), Environmentally Friendly Green Buildings Association was launched (Külekçi, 2017).

- In 2008, the Energy Efficiency Law No. 5627 was entered into force by the ministry of urbanization for environmental sensitive companies to receive international certificates such as LEED and BREEAM (Külekçi, 2017).
- Another certification system, Sustainable Energy Efficient Buildings (SEEB-TR), has started its studies at Mimar Sinan Fine Arts University (MSGSU) (Külekçi, 2017).

4.6. Cost efficiency

Construction of green roofs comes with a high cost upfront but in the long run, it provides long-term savings and a better quality of life. The cost consists of construction and maintenance during the lifetime of the green roof. The initial cost of construction was high for all the three projects studied in chapter 3. It is believed that the projects have saved energy costs however there are no proven records for any of the projects.

4.7. Thermal comfort and Energy efficiency

Green roofs around the world have proven to be energy efficient and increase indoor thermal comfort. In interviews with Lineeverdi of 25 Verde and Pharos architects of French embassy, both mentioned that they believe the green roofs provide indoor thermal comfort reducing the use of air conditioning which leads to energy efficiency in the long run. However, there are no records taken as yet. Same applies for Meydan retail complex in Istanbul.

For the 25 Verde project in Torino, the structure was given the energy performance class A designation and has been found to be in compliance with the municipal building code of Turin (climate-adapt, 2022). Because it had green roofs, storm water retention and reuse, average natural lighting performance, passive solar protection above required standards and norms, and thermal insulation and inertia, it was granted a 20 percent tax rebate during licensing (climate-adapt, 2022).

The French embassy in Nairobi has obtained a LEED certificate (Pharos architects, 2022) which proves that the building is energy efficient and sustainable while Meydan Retail shopping complex in Istanbul received an award in the 2008 Turkey Program Process Category of European Environmental Awards (Beyhan and Erbas, 2013).

4.8. Case study comparisons

The summary of the case studies research and comparison is portrayed in Table 2.

	FRENCH EMBASSY, NAIROBI	25 VERDE, TORINO	MEYDAN RETAIL COMPLEX, ISTANBUL
BUILDING FEATURES			
BUILDING TYPE	Embassy	Residential complex	Shopping center
BUILDING AREA	3224 m^2	7000 m^2	120,000 m^2
CONSTRUCTION YEAR	2017	2012	2007
GREEN ROOF FEATURES			
GREEN ROOF TYPE	Semi-intensive	Intensive	Extensive and intensive
GREEN ROOF AREA	3224 m^2	4000 m^2 including terraces	55,000 m^2
ROOF SLOPE	Slight slope	Flat roof	Multiple slopes
ROOF USE	Private	Private	Public
ACCESSIBILITY	Not accessible	accessible	Partly accessible
TYPE OF VEGETATION	Sedums, shrubs, local aloe and grasses	grasses, trees, orchards, flowers and fruit trees	meadows, flower plantations, grasses, bushes and shrubs
OUTCOME			
SOCIAL PERCEPTION	uncommon	common	common
POLICIES/REGULATIONS	No current policies on green roofs	UNI 11235:2015 “guidelines for the design, execution, inspection and maintenance of green roofs”	Istanbul 2018 regulation 30426 created a mandate for green roof implementation
POTENTIAL BENEFITS	-increase biodiversity -slows rain water run off -stabilizes building temperature increasing thermal insulation	-slows rain water run off -stabilizes building temperature increasing thermal insulation	-increase biodiversity -slows rain water run off -stabilizes building temperature by

	-reduces urban heat island effect -aesthetics	-reduces urban heat island effect -aesthetics -urban agriculture	increasing thermal insulation -reduces urban heat island effect -aesthetics -reduces pollution -reduces ambient noise
CERTIFICATION/ AWARDS	LEED certificate	Class A energy certification according to municipality building code of Turin	2008 Turkey Program Process Category of European Environmental Awards

Table 2. Green roof properties and comparison of three case studies
By author based on data researched in chapter 3

4.9. Innovative system

Green roofs have proven to reduce the effects of urbanization and climate change with the multiple benefits they provide. Another innovative way of maximizing the energy savings and cost is the integration of solar panels with the green roofs. The use of solar energy adds to the energy efficiency of the building. This concept has started to be adapted in the western countries. One of the system providers are ZinCo, Germany where they integrate solar energy into green roofs and produces synergies, whether it is for producing photovoltaic electricity or for uses including heating and hot water. The Solar Base Frames' height creates sufficient space between the substrate layer and the solar panels, allowing for adequate maintenance as well as enough sunlight and moisture for the plants (ZinCo, 2022). The temperature of the solar modules and the ambient air temperature have an impact on their performance. When the solar modules are combined with the green roof, they perform better. The ambient air temperature is cooled as a result of evaporation at the plant level, which enhances the efficiency of photovoltaic cells (ZinCo, 2022).

Fig. 59 Solar base and photovoltaic panel
Retrieved from ZinCo, (2022)

Fig. 60 Solar panels integrated with green roof
Retrieved from ZinCo, (2022)

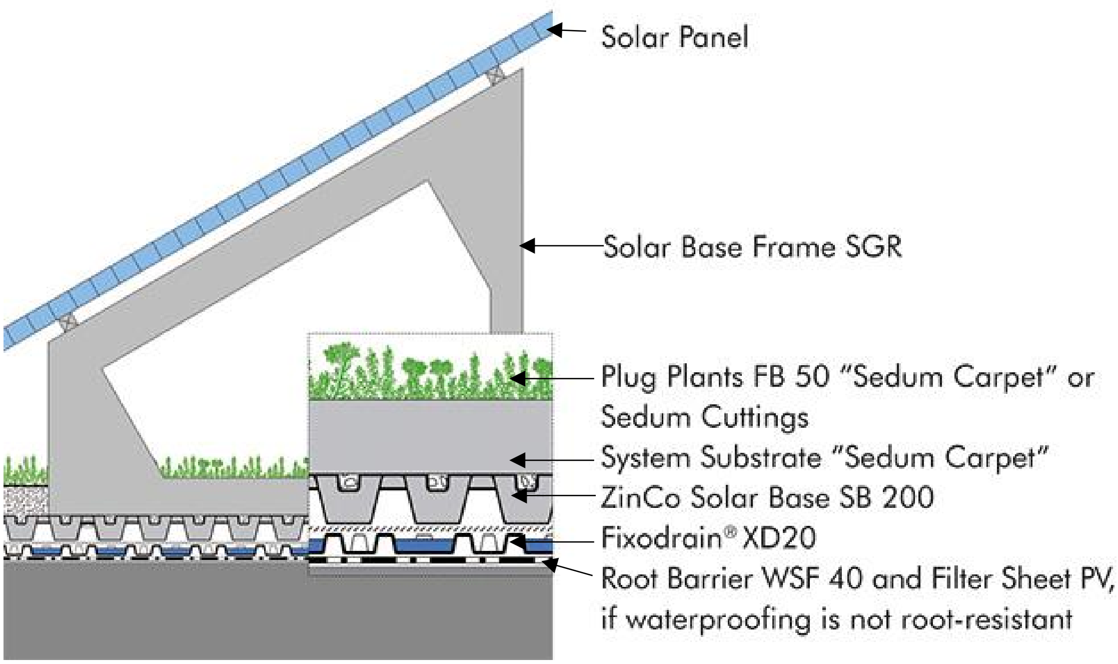


Fig. 61 Solar panels integration system build up
Retrieved from ZinCo, (2022)

CHAPTER 5

CONCLUSION

5. CONCLUSION

Urbanization has led to the loss of green spaces in urban cities. A strategy to increase greenery in urban areas is the use of green roofs. As discussed in the research, green roofs have proven to benefit the environment and come with several advantages. Nairobi, Turin and Istanbul are metropolitan cities facing climate change due to urbanization effects. All three cities have the presence green roofs. However, they are uncommon in Nairobi compared to Turin and Istanbul. Turin has the most number of green roofs out of the three cities. With Istanbul being the largest in area, the number of green roofs are not abundant in comparison with Turin. This creates a need for increase in implementation of green roofs.

One of the observation of the comparison between the case studies was that there are no regulations, policies or mandates for the adoption and maintenance of green roofs in the city of Nairobi. The existing few green roofs in Nairobi have been designed and constructed using conventional methods without the knowledge of the county government of Nairobi. In order to achieve substantial green roofs in Nairobi, there is need for generation of policies and planning.

It is noted that there is a research gap between underdeveloped and developed countries where more research has been conducted in areas with cold climates while there is a need for research in different geographical and climatic areas. In addition, to increase social perception of green roofs, people need to be educated on the adoption and benefits of green roofs. One way of encouraging people to implement green roofs is for the government and stakeholders to provide incentives to building owners. This will lead to the implementation of green roofs on a larger scale.

The quantifiable benefits of green roofs in the case studies are difficult to be obtained. However theoretically, the projects are said to include benefits such as reduced temperatures and reduction of storm water runoff. The storm water should be utilized in household functions and plant irrigations. It is also difficult to calculate the economic impact of green roofs therefore, there is need for studies to come up with ways to easily assess the economic impacts of green roofs such as using online calculators.

The research also talks about innovative ways to enhance the energy performance of a building integrated with green roofs. The use of solar panels with the green roof improve the energy efficiency of a building .The idea that one must choose between a solar system and a green roof is mistaken belief. The solar modules perform better when combined with a green roof. This system has been implemented in developed countries however it is still new. To conclude, green roofs implementation is important in urban cities around the world to reduce urban heat island effect and mitigate climate change creating sustainable and livable cities for inhabitants.

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6. APPENDICES

6.1. Interview questions for the Green roof at the French Embassy Nairobi.

Name: Andrew

Firm: Pharos Architects, Nairobi

1. What was the purpose of designing a green roof on the building?
2. Did you follow any kind of government regulations or policies to construct the green roof?
3. Do you think the concept of green roofs is known by the people of Nairobi?
4. What factors were considered when designing the green roof?
5. What type of vegetation is planted on the roof? And what was the reason of selection of that kind of vegetation?
6. Is the green roof accessible?
7. What were the challenges faced when constructing the green roof?
8. How often does the green roof require maintenance?
9. Do you think the green roof has been cost effective since the time of construction?
10. Has the green roof shown any advantage in energy saving of the building?
11. What other impacts has the green roof had on the building?
12. As an architect, what do you think the prospects are for designing and constructing green roofs in Nairobi?

6.1. Interview questions for the Green roof of 25 Verde in Turin.

Name: Stefania and Chiara

Firm: Lineeverdi Landscape architects

1. What was the importance of designing a green roof on the building?
2. Did you follow any kind of government regulations or policies to construct the green roof?
3. Do you think the concept of green roofs is known by the people of Torino?
4. What factors were considered when designing the green roof?
5. What type of vegetation is planted on the roof? And what was the reason of selection of that kind of vegetation?
6. Is the green roof accessible?
7. What were the challenges faced when constructing the green roof?
8. How often does the green roof require maintenance?
9. Do you think the green roof has been cost effective since the time of construction?
10. Has the green roof shown any advantage in energy saving of the building? If so, do you have any records?
11. What other impacts has the green roof had on the building?
12. What other strategies do you recommend to improve the use of green roofs?