Evaluation of Green Roof Technology in Egypt

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Evaluation of Green Roof Technology in Egypt

A Thesis Submitted by

Hend Ahmed Hassan Ali Abada

TO THE

Master of Sustainable Development

Spring 2023

in partial fulfillment of the requirements for the degree of sustainable development master
Declaration of Authorship

I, Hend Abada, declare that this thesis titled, “Evaluation of Green Roof Technology in Egypt” and the work presented in it are my own. I confirm that:

• This work was done wholly or mainly while in candidature for a research degree at this University.

• Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.

• Where I have consulted the published work of others, this is always clearly attributed.

• Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

• I have acknowledged all main sources of help.

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Date: 15/5/2023
Abstract

A green roof is a well-known technology worldwide that provides many social, economic, and environmental benefits. In Egypt, green roofs are still a new construction practice where most stakeholders lack business and technical expertise within this emerging industry. This research is concerned with assessing this emerging technology within its contemporary context, Egypt, and testing its feasibility within the physical condition of the Egyptian buildings and the social and economic conditions of the Egyptians. This study starts by presenting intensive information about green roof technology and reviewing the literature on green roofs within the Egyptian context. A grounded methodology is used to get accurate information about the green roof market in Egypt. The study estimates the size of the green roof market in Egypt considering the building type and condition, its associated roof size, its potential for being a green roof, and its users' socioeconomic situation. In addition, personal interviews with green roof users and Egyptian market stakeholders were conducted to understand the challenges throughout different project phases better. This research presented the benefits of green roofs to its users and estimated the potential benefits if this technology is implemented nationwide. The research gives a detailed perspective on Egypt's green roof industry for all stakeholders, decision-makers, and policymakers they base their decisions upon.

Keywords: Green Roof, Sustainable Landscape, Sustainable Development, Green Infrastructure
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Chapter 1

Introduction

1.1 General Background

A green roof is a "roof or a deck designed to provide urban greening for the buildings, people or the environment" (Magill et al., 2011). Green roofs are referred to as vegetated roofs, cool roofs, eco-roofs, roof gardens, or living roofs. They are considered effective architectural solutions for implementing sustainable development goals. Their benefits vary from environmental to social and economic. Having a unique social space on the roof is aesthetically appealing instead of having it unused (Green Roofs in Cairo, 2009). At the same time, it increases the property value, improving roof insulation, reducing energy consumption, and increasing noise insulation. (Living Architecture: Green Roofs and Walls, 2011). Environmentally, a green roof provides a new wildlife habitat within the urban setting, and it is a resilient method against climate change, urban heat islands, and pollution. Detailed information about the benefits of green roofs is provided in section 2.3.

Egypt, the third most populated population in Africa after Nigeria and Ethiopia and fourteen worldwide, will have a population of 102 million people in 2022. Its population is in a continuous increase of 1.75% in 2022. Even though Egypt has a land use of 955,450, most of the population is condensed within 44 thousand square kilometers along the Nile River. Its largest cities are Cairo, the capital, Giza, and Alexandria. Cairo has the highest number of people, 10.902 million people, as estimated in 2009. The country has a density of 84 people per square kilometer, while Cairo has the heaviest population of 46,349 people per square kilometer. In addition, the urbanization rate is 2.1% annually (Egypt Population, n.d.).
1.2 Research Motivation

The research aims to reduce the gap between academics and reality. The amount of research done on the green roof, especially in the Egyptian context, is low and not current. As the green roof market is emerging in Egypt, rapid development occurs without documentation or correlation with recent academic research. Therefore, this research would like to understand the actual conditions of green roofs in Egypt through the perspective of different stakeholders and ties it to the existing academic research in the Egyptian context. Below is a list of questions that the author is willing to answer in this research:

- What is the size of the green roof market in Egypt and its rate of evolution?
- Can all Egyptian buildings structurally stand on green roofs? If not, which building types would be more suitable for green roof implementation, and can these buildings categorize according to their construction conditions?
- Which green roof type would be suitable for each category of Egyptian buildings?
- What is the cost of green roof technology? Which socioeconomic group within Egypt can afford its implementation?
- Is any modification needed within the existing green roof products to fit the Egyptian culture?
- What are the motives for implementing green roofs from the aspect of the users and the challenges the implementer face during the different phases of design and construction?
- How could the Egyptian environment benefit from implementing green roof technology?

1.3 Research Objective and Scope

The research main objective is understanding the whole potential of green roof in Egypt and the challenges that face the immigration of this technology to Egypt. This research would help penetrate the green roof technology into the Egyptian market. It would provide the required technical and business information to develop a green roof industry in Egypt. Studying the different types of buildings in Egypt and choosing the
suitable green roof technology based on the socio-economical class of the users and the building structure would allow all stakeholders to understand the physical environment of Egypt and the users' financial capabilities. Also, measuring the size of the potential Egyptian market for the green roof industry images all stakeholders of the market conditions and the expected revenue. Surveying users of existing green roofs in Egypt show them their customer expectation and problems to tackle easily within their green roof designs.

This research does not only benefit stakeholders within the green roof industry. However, it also shows the policymakers and decision-makers the benefits green roof brings to the Egyptian culture and physical environment. Showing its social, economic, and environmental benefits within the Egyptian context can convince them to include green roofs within the Egyptian codes and their construction practices. For example, a real estate developer would understand the economic benefits he would possess if he added a green roof to one of his projects while considering his customers' needs, as mentioned in the research. He could estimate the expected increase in the building units' price. The study would show the details of the users' experience on a green roof and their desires, likes, and dislikes. This can provide a full image of the customers' personas and needs that decision-makers can use as a base for their marketing plan.

1.4 Research Methodology

This research aims to question the adaptability of the green roof concept within the physical environment of Egypt and its acceptance by the community. Targeting this aspect and getting a good understanding of the reality, the followings are the objectives of this research and the methodology used for fulfilling each.

1.1.4 Market Size Estimation

This objective would be done through the statistical data collection & interpretation method. This would be done through three successive steps stated as follows:
- Reviewing the existing information about the buildings in Egypt & the area of their associated roofs; would require collecting data from Egyptian authorities and accredited databases
- Categorization of these roofs according to construction material, their geographical location & building use, and the socioeconomic status of its users.
- Evaluating the number of roofs that have the potential of being a green roof

Not every green roof can be implemented on any building in Egypt for some structural and economic reasons, as not all Egyptian buildings can stand the associated loads of green roofs. Roofs are built with reinforced concrete, steel, or rice straw. These different materials have different structural strengths. Eventually, some might not stand loads of green roofs, and others can only stand one type of green roof. Even if the building can stand a kind of green roof technology, the residents might not be able to afford the implementation cost of green roofs. Therefore, structural and socioeconomic analysis is required to identify the actual size of green roof technology in Egypt.

Questioning Egyptian culture is essential. Every country has its habits and beliefs, requiring a green roof with a particular feature for specific uses. Egyptians might ask for an intensive green roof to plant trees for privacy concerns. Also, the reason for implementing a green roof might differ from one country to another. Some countries might be interested in its economic benefits rather than its environmental ones. Understanding the relationship between Egyptian culture and the green roof would be the start of any marketing campaign in the green roof industry. Realizing the potential customers' needs and desires would ease the technology's penetration within Egypt.

Also, understanding the effect of green roofs on the environment is essential. The impact of green roofs in Egypt is questionable. Most of the materials are mainly manufactured overseas. International transportation would cause many carbon emissions. Therefore, calculating the carbon footprint for implementing green roofs in Egypt is essential to understand its environmental worth and whether it would digest much more carbon during its life span than its transportation.
2.1.4 Understanding the Social, Economic, and Environmental Benefits of Green Roofs in Egypt

This objective is fulfilled through qualitative research, which gets valuable information about the effect of Egyptian culture on green roof technology. The targeted people are both the users of green roof projects and their implementers. The research is done by observing the people's interaction on the roof and having one-on-one interviews with some of these users and implementers. The researcher would try to find repetitive patterns within discussions and similarities between different projects. The researcher believes these patterns would be mainly due to cultural similarity and context challenges. It can present both the users' motives for having a green roof and the challenges the implementers face in the Egyptian context. However, the socio-economical difference would be considered as it would change the needs and beliefs of each user.

Other inquiries would be about the economics the users and real estate developers expect from the green roof implementation or already have proof of it. A reduction in electricity bills or increased property value is questioned, showing its actual amount and comparing the situation before and after the implementation. This can present the return on the invested rate of implementing a green roof in Egypt. Also, the users are asked about their wildlife observation while using the green roof. Understanding the effect of green roofs on the environment is essential, especially in the dense context of urban cities.

The methodology is justifiable as no existing research estimates the number of roofs that can be converted to green roofs in Egypt. (Gawad, 2014) assumes that as all the Egyptian roofs are flat, they can be used for roofing farming or green roofs. Hussain et al., (2015) recommend the structural condition for a building that can be converted to a green roof. No one tried collecting data to test the actual market size of green roofs in Egypt. Estimating the green roof by reviewing the potential number of roofs that can be converted to green roofs can give investors and decision-makers a clear image. This industry is still emerging in Egypt, and more information is required about its whole potential.

(Ragab & Abdelrafi, 2020) calculated the cost of the green roof using the prices brought from a Chinese online platform. This would not give an accurate cost estimate as
these prices might not include the Egyptian taxes and the shipment fees. Also, the author did not consider the change in materials for each green roof system and treated them all as one. For each system the cost of each green roof system would be estimated according to its requirements. The total cost would include supply prices from local suppliers, all indirect costs, and transportation costs.

As for testing the socioeconomic outcome of a green roof, researchers such as (Gawad, 2014) and (Abd El-Hafeez et al., 2016) mainly depend on reviewing literature only. (Ibrahim, 2018) depends on surveying the people about their suspected benefits of the green roof. The author believes interviewing green roof users would give a more grounded perspective rather than exploring people who have not visited a green roof once. The users would have a grounded opinion about their green roof experience rather than guesses and irrational beliefs.

1.5 Organization of Chapters

Chapter 1 presents a general overview of the whole research giving general information about green roof technology and the research context, Egypt. It emphasizes the research scope, objectives, and used methodologies.

Chapter 2 builds an intensive understanding of the green roof concept through a detailed literature review of the green roof technologies, including its history, benefits and types, international practices and uses, and some international green roof projects.

Chapter 3 is a qualitative collection of data about the green roof market in Egypt; presenting the existing and planned green roof projects, green roof companies, their technologies, and work.

Chapter 4 presents the market size of green roofs in Egypt through a statistical analysis of Egyptian buildings and their use distribution. Also, it presents an estimation for the potential benefits of implementing the green roof technology nationwide.

Chapter 5 presents detailed information about the existing projects in Egypt through a qualitative method. It presents the procedures for collecting this data from the different
stakeholders within both the construction and green roof market to the interviews results and analysis.

Chapter 6 presents a list of recommendations to decision-makers and stakeholders within the green roof market, including the governmental sector, real estate developers, and clients.
Chapter 2

Literature Review

2.1 Introduction

Nowadays, people tend to migrate from rural to urban areas, causing urban areas to evolve rapidly. This huge urbanization process would cause a lot of environmental problems. The construction materials used in building practices are not environmentally friendly; the materials increase the temperature of the whole area. During the day, these materials absorb the solar heat and release it at night. With time, this thermal process increases the temperature of the whole planet. Also, urbanization demolishes a lot of natural habitats. This is causing a disturbance to the natural ecosystem within the country and the surrounding areas. Another issue caused by urbanization is Air Pollution, which is highly harmful to human health and the continuity of the main kind (Feisal & Haron, n.d.).

As the world population increases, their energy demand is rising too, causing much pressure on the power supply system. Both the residential and commercial sectors are consuming a considerable amount of energy. In addition, there is a global tendency to reduce energy consumption to compensate the future demand and decrease the pollution caused by fossil fuels. 64% of energy production is produced from fossil fuels worldwide (Roser & Ritchie, 2017). As for Egypt, the percentage is even higher and reached 95% of the country’s energy production in 2016 (Egypt, 2018).

Egypt is scarce in green areas, especially in large cities like Cairo. The number of green areas in Cairo is relatively meager compared to other cities; 0.3 square meters per person was estimated in 2009 (Attia & Amer, 2009). As the Egyptian population is increasing and the urban areas are becoming denser and denser, this portion of green areas will decrease. Even a couple of parks in this metropolitan city are not within walking distance of all its citizens. On the other hand, most of our residential buildings
are flat-roofed, unused, or used as storage areas. It was great potential for being used as a private social space (Feisal & Haron, n.d.).

The following presents a belief background of the green roof and its benefits which the reader requires to understand the aims of this project

2.2 Green Roof Definition and History

A green roof is defined as a "roof or a deck designed to provide urban greening for the buildings, people, or the environment" (Magill et al., 2011). The green roof can be called vegetated roofs, cool roofs, eco-roofs, roof gardens, or living roofs. Having greenery on roofs is an old technique for insulating improvement and reducing urbanization's drawbacks. The hanging gardens of Babylon are one of the most famous ancient green roofs constructed around 500 BCE. However, modern green roof technology started in Germany in the 1960s to reduce energy consumption within the building. In the 1980s, the market for green roofs in German expanded rapidly, and the German guideline for a green roof, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), published its first edition. They developed several additions since then (Shafique et al., 2018).

Right now, many developed countries like the USA, Canada, Japan, Hong Kong, Australia, and South Korea are initiating the application of green roof technology on top of new and existing buildings. Various countries encourage people to implement green roofs through financial incentives or water or property fee reductions due to various environmental, economic, and social benefits from the green roof. Policies for the green roof application are inscribed (Shafique et al., 2018).

2.3 Green Roofs Benefits

The benefits of green roofs can be characterized according to their social, environmental, and economic aspects, as stated as follows:

1.2.3 Social Aspect
Aesthetic appeal; green roofs beautify the built environment without any massive alteration. A green roof can be implemented upon most of the built structures reducing the users' pains of diving through dense traffic to reach parks and instantly connecting
the user with the natural environment within his home. This connection with the natural environment would positively affect the user's physical and psychological health (Green Roofs in Cairo, 2009).

Unique social space; green roof provides an excellent opportunity for residents to interact with each other and nature. The whole family would share a sense of belonging and responsibility towards their green roof as long as they continuously use it. Having birthday parties, engagement parties, or even breakfast daily would strengthen their bond with the place and emotional and social intimacy with their family and friends. Their consideration of the place's cleanness and its maintenance works would ensure an infinite opportunity of having their own social space without any financial pressure. Also, children can interact with nature by doing agricultural activities to increase their awareness and knowledge about the natural environment (Green Roofs in Cairo, 2009).

Educational tools about agriculture; combining agriculture with green roof technology can be used as an educational tool. In dense cities, people are not aware of basic farming skills. These roofs can be treated as small farming units where people can experience the whole farming process from seeding to harvesting. Adding a green roof to schools has provided a social place and an educational hub. On the other hand, with the increased population of the world, green roofs should be considered one of the solutions for providing food, especially within the expanding urban areas (Walters & Midden, 2018).

Health improvement and therapeutical method; the green roof can help improve its users' mental and physical health. Also, even if the green roof is not accessible, having a visual connection with the green roof can help in general well-being. The green roof is part of many hospitals retrofit plans as it appears to help patients recover and get better (Health, n.d.), on the other hand. Cities can be stressful due to the lack of greenery, and green roofs can subsidies conventional greenery and improve the mental health of its residents (Rezaei et al., 2021).

Noise reduction; the green roof can absorb sound waves and eventually reduce the sound level. Significantly, the vegetation layer plays an essential part in noise reduction. It has a high absorption coefficient. Green roofs can decrease the noise frequency by 10 – 20 dB
(Shafique et al., 2018). Several airports, like the Frankfurt airport, implemented green roofs as a method of noise reduction (Manso et al., 2020).

### 2.2.3 Economic Aspect

Rainwater retention: the green roof is considered an effective method for rainwater management as the system holds a large amount of water. This can reduce the number of flooding events and help maintain the rainfall peak flow and runoff. The performance of the green roof can vary according to the system materials and components and its implementation allocation. The moisture content of the soil and its thickness, the plants used, and the type of drainage materials identify the system's capabilities for holding the rainwater. Also, the roof's slope and rainfall intensity affects the system's performance. 55% to 88% variation occupy the water retention of the green roof depending on its location worldwide (Shafique et al., 2018).

Water quality enchantment: (Shafique et al., 2018) review shows opposing literature about the performance of the green roof in enhancing the quality of water. It can positively or negatively adjust the amount of heavy materials and pollutants within the rainwater. This mainly depends on several factors, including any pollution sources around the green roof, the type of green roof, whether intensive or extensive, the lifetime of the green roof, the type of growing media and its organic content, and the fertilizers used.

Property value increase; Properties with accessible green roofs are subjected to a 20 percent property value in North America. Also, the whole neighborhood benefits financially. The property value of Buildings overlooking the green roof also increases as it is considered a green natural view (Living Architecture: Green Roofs and Walls, 2011).

Energy consumption reduction; A green roof provides an extra insulation layer to the building rooftop reducing the electricity demand for most upper floors. This insulation provides a comfortable, livable atmosphere for the residents as it isolates one of the main building skins, the roof, from the direct solar radiation all year long. Two Celsius decrease in most upper flows is expected. Therefore, the cooling expenses are reduced by 10 – 40 % depending on the climatic conditions and structural elements (Living Architecture: Green Roofs and Walls, 2011).
A food security source and Revenue provider: As the urban population increases, empty spaces such as roofs can secure the food supply chain by providing more crop growth areas. Also, a green roof can provide an extra source of income for the building residences if edible crops are planted. Different types of plants require different depths of soil to grow well. Therefore, both the intensive and extensive systems can be used; leafy plants like lettuce can be planted with the extensive system as they can be planted in less than 15 cm. while vegetables like tomato and cucumber require higher soil depth. Ultimately, intensive systems will be used (Walters & Midden, 2018).

3.2.3 Environmental Aspect

New habitat providence; the natural environment has lost many features in urban cities (Ibrahim, 2018). The urban sprawl has negatively affected the animals' migration colliders and the existence of the natural ecosystem (Sharaf, 2017). A green roof can help create a mimic similar to the natural habitat; using native plants is vital to lift the creation of natural habitat for little creatures like birds and insects and boost biodiversity (Ibrahim, 2018). Also, a green roof can provide a resting point for migrating birds in the urban context (Sharaf, 2017).

Temperature reduction and the migration of the heat island effect; the air and surface temperature are much higher compared to suburban and rural areas. This phenomenon is called the heat island effect. One of its main reasons is the reduction of green areas and excessive use of concrete, stone, and bituminous membranes. The materials absorb heat temperature during the day and release it during the night, increasing the temperature of the whole area as presented in Figure 1 (Berardi et al., 2013). This increase in temperature boosts the users' energy demand, highly depending on air conditioning systems for cooling their houses. It adds more pressure on the city's energy resources. However, green areas in rural areas increase the air temperature slightly due to the evaporation process of the water instead. Green roofs can mimic the act of green areas in rural areas and helps in reducing the temperature in urban areas. In Europe, research shows that construction materials can differ in the building involvement within the heat island effects. They are having a 34 °C day, for example. The surface temperature of a concrete slab and steel frame can reach 46.5 °C and 55.8 °C, respectively. While a green roof has caused a rise to
39 °C, which is still close to the air temperature, and does not contribute to the temperature rise at night like the concrete and steel materials do (Suszanowicz & Więcek, 2019). (Alexandri & Jones, 2006) believes that the hotter and drier the climate, the more the urban setting can benefit from implementing green roofs. The research is conducted through situational analysis of extensive green roofs. Riyadh in Saudi Arabia presented a 3.6 Celsius decrease in the air temperature at a one-meter height from the roof floor. Also, 8.5 Celsius is documented for the roof surface temperature.

Improvement of air quality; urban cities are contaminated by fine harmful dust particles (CO2), which cause human discomfort and pollute the environment. The plant types indicate the green roof’s performance in improving air quality. Trees proved to be more efficient than shrubs and lawns in capturing air pollutants; therefore, intensive green roofs are more effective in air quality improvement (Shafique et al., 2018). For example, a green roof can help capture CO2 directly and indirectly. Directly, Plants and soil capture the atmospheric carbon through the plants’ photosynthesis process and the soil storage capacities. Therefore, the plant and soil characteristics indicate the green roof’s total performance. The plant types and leaf area index (LAI), the ratio of the plants’ coverage to the ground area, soil depth, and moisture content are some of the affecting factors. Indirectly, a green roof insulates the roof, reducing the total energy consumption of the

Figure 1: Comparison between the thermal performance of conventional roof Vs. green roof (Berardi et al., 2013)
building. This helps decrease the burning of fossil fuels used for producing building energy and its concurrent emissions (Shafique et al., 2020).

(Shafique et al., 2020) reviewed the available publications about the amount of carbon sequestrated per unit meter of the green roof from 2000 to March 2019. The different amounts and calculation methods within different testing locations (Spain, USA, China, Italy) were mentioned. These values range from 0.313 – 1.88 of kg CO₂ per square meter of green roof annually. In addition, other publications express the carbon emissions in terms of kg C per square meter of green roof annually. Their range varies from 0.28 – 9.82. (Kuronuma et al., 2018) also present quantitative data for the direct and indirect aspects where the green roof can help reduce carbon dioxide emissions. Directly around 2.5 kg CO₂ / m² is sequestrated by the plants annually. Indirectly, a range between 1.703 – 1.889 kg CO₂ / m² annually can be saved by subsidizing the saved cooling and heating energy. The type of plants does not differ much in Carbon dioxide sequestration amounts.

Besides the social, economic, and environmental benefits suggested previously, a green roof can help a building obtain green building certifications. A potential of nine points can be achieved in Leadership in Energy and Environmental Design (LEED), a US green building certification. These points are allocated for the technological restoration of natural habitat, maximizing open space, stormwater management, migrating the heat island effect, and having a water-efficient landscape (Fauzi & Abdul Malek, 2013).

In Addition, green roofs bond strongly with the United Nations’ sustainable developments goals of 2023. As shown in Figure 2, green roof satisfies 12 out of 17 SDGs and discussed as follows (Rahman et al., n.d.):

- SDG 2: Zero Hunger & SDG 12: Responsible Consumption and Production; edible crops can be provided through green roofs
- SDG 3: Good Health and Well-Being; the natural environment improves physical and mental wellbeing
- SDG 6: Clean water and sanitation; rainwater is harvested through green roof to the usage for non-potable domestic use, it reduces both the supply and sanitized water within the governmental system.
- SDG 7: Affordable and Clean Energy; as green roof provides a thermal insulation to the building, it can save electric energy. Also, the water stored within the green roof can provide a source of electricity if turbines are used.

- SDG 8: Decent Work and Economic Growth; new job opportunities are created within the green roof ecosystem

- SDG 9: Industry, Innovation, and Infrastructure; new materials and techniques are continuously developed within the green roof market

- SDG 11: Sustainable Cities and Communities; large implementation of the green roof technology can provide a greenery environment and more sustainable urban areas

- SDG 13: Climate Action; green roofs help in purifying the atmosphere from carbon di-oxide and provide oxygen.

- SDG 14: Life Below Water; as green roof filters the irrigated water, it helps in purifying the wasted water

- SDG 15: Life on Land; green roof provides an eco-system for birds and insects

- SDG 17: Partnerships for the Goals; local and international partnerships are used for the development of materials and techniques.

Figure 2: United Nations’ Sustainable Development Goals Vs green roof technology (Rahman et al., n.d.)
2.4 Green Roofs Types

There are three main types of green roofs; intensive, simple intensive (sometimes referred to as semi-intensive), and extensive. These types mainly differ in soil depth, types of plants, irrigation requirements, maintenance, general use, and cost (FFL, 2018). Within this section, these differences will be presented.

1.2.4 Intensive Green Roof

The intensive system is more like a mini garden used for socializing purposes. Therefore, the system height ranges between 120 – 250 mm. trees, shrubs, and perennials are planted to fulfill its aesthetical purposes (Hussain et al., 2015). This type of plantation requires concentrated irrigation and maintenance to be adequately sustained (FFL, 2018). The system can add up to 500 kg/m² extra weight to the structural roof system. a load analysis is required to prevent any damage to the building structure (Hussain et al., 2015). The substrate is over 12 in. (30 cm) (Shafique et al., 2018).

2.2.4 Simple Intensive Green Roof

The design of this green roof system is more straightforward than the intensive one, as the plant variation is limited to groundcovers, grasses, perennials, and shrubs (Hussain et al., 2015). Around 120 – 200 kg/m² is added to the building loads. The system height ranges between 120 and 250 mm (Hussain et al., 2015), while substrate depth varies between 6 and 12 inches (Shafique et al., 2018). The required irrigation and maintenance are moderate compared to other systems.

3.2.4 Extensive Green Roof

This system is considered the most suitable for many building load restrictions (Shafique et al., 2018) as it only adds 60 - 150 kg/m² extra weight to the roof (Hussain et al., 2015). Extensive green roofs are characterized by their low soil substrate depth ranging between 3 – 4 inches (7 – 10 cm). It is considered the cheapest green roof type, requiring low capital cost and minimal maintenance. Sedum species are the most common vegetation used as it typically needs no irrigation (Shafique et al., 2018).

As previously described within each green roof type, the green roof adds to the static loads of the buildings. The system weight with saturated soil and its plants identifies
the static load, while any extra water and its guests are considered its dynamic ones. It is much easier to consider the green roof loads during the design phase before the start of the building construction. There might be a change in the structural design of the roof. However, it is essential for retrofit projects to stick to the roof’s structural requirements to avoid any structural failure (Velazquez, 2010).

2.5 Green Roofs Implementation Method and Materials

There are two primary implementation methods for green roofs upon which the materials are selected (Hui & Chan, 2008). The following presents these methods, their layers, and their use (Cascone, 2019).

1.2.5 Conventional Green Roofs

A simple illustration of the rooftop system is shown in Figure 3, which shows the main components required for implementing a fully functional system. A brief description is stated as follows (Suszanowicz & Więcek, 2019):

![Diagram of conventional green roof components](image)

Figure 3: Components of conventional green roof type (Suszanowicz & Więcek, 2019),
Source: author's design
- Vapor control layer helps in protecting the building from the consequences of condensation of moist air, which can cause damage to the structure (GREEN ROOF, 2011)

- Waterproofing layer

Its primary function is protecting the structure from water penetration and leakage. However, the green roof materials above protect it from solar radiation and heat. As its function is essential to the building structure’s safety, and maintaining this layer after completing the whole green roof construction is destructive, selecting a proper material is essential. Here are several important characteristics to be questioned to ensure the functionality and durability of this layer (Cascone, 2019):

- water tightness; the ability of the layer to hold the water used within the system
- solar radiation resilience; during the construction process of the green roof, this layer is faced with excessive solar radiation
- cold flexibility; its flexibility with temperature changes
- resistance to static loads; its capability to stand the fixed load of the green roof system or furniture pieces.
- artificial aging; its corrosion and deterioration if exposed to solar radiation
- roots resistance; if a root barrier layer is not part of the system, the waterproofing layer has to be able to defend plants' roots. The roots can penetrate the waterproofing membrane and damage it. However, if a root barrier is constructed, there is no need to check this property.
- biological and chemical resilience; the green roof system will expose the waterproofing membrane to biological and chemical components, and its resistance to these components has to be questioned.

There are two main types of waterproofing systems ("Green Roof Systems," n.d.):

Sheet applied Membranes, sheets of membranes differ within the welding process; some are self-adhesive, and others require liquid adhesive or torch. Their uniform thickness characterizes them. However, they require cutting to fit the area required and a particular focus on their welding process as it might affect the efficiency of the membrane (Sheet vs. Fluid Applied Waterproofing, 2020). The following are some of its types:
- Bituminous membranes are commonly used as waterproofing membranes worldwide; they are characterized by the mixed polymer mixed with bitumen, either elastomeric or plastomeric. Elastomeric polymer obtains flexibility and elasticity at low temperatures, while plastomeric polymer can withstand UV exposure and stabilize at high temperatures (Cascone, 2019). However, there is a concern about its long-term performance when used for green roof applications. Therefore, it is less likely to be used (whittemore, 2007).

- Thermoplastic Polyvinyl Chloride (PVC) is a thermoplastic sheet welded using hot air. It is used widely in Europe and the United States within green roof applications (whittemore, 2007).

- Other types include thermoplastic polyolefin (TPO) and ethylene-propylene-diene monomer (EPDM). TPO is still newly used for the green roof (whittemore, 2007).

Liquid-applied membranes; lightweight seamless membranes allow their application on large areas without overlapping and bonding procedures (Berenguel, 2022). It might not have the same thickness consistency as it is challenging to monitor the thickness of the applied liquid (Sheet vs. Fluid Applied Waterproofing, 2020). It requires a considerable amount of time for drying. Some types are described as follows ("Green Roof Systems," n.d.):

- Rubberized Asphalt is applied as a hot liquid and strengthened with a suitable fabric
- Polyurethane Elastomers are a spray applied that create a seamless waterproofing layer.

There is obligatory to test the efficiency of the waterproofing before proceeding with the rest of the green roof installment. Fixing any breach within the membranes after installation is difficult to allocate, requires the deterioration of the whole system, and is expensive. The following are the available types of waterproofing tests (Capolino, 2017):

- Flood testing is the most primitive method of testing. It requires ponding the tested area with water for 12-48 hours. If leakage is observed from the lower floor, another testing method or visual checking is needed to allocate the breach.
- Spray testing uses fixed water flow to detect the point of leakage. It is used when flood tests or any other method is difficult due to the structural composition. Preferably walls, pitched roofs, and sloped glazing are tested using this method.
- Capacitance testing detects the moisture content rather than the location of the leakage. This test an electric field is established on the roof, and an electricity meter is used to determine the electric strength at each point. It can help in interpreting the breach location. However, it is not absolute. The high moisture content can be caused due to condensation beneath the waterproofing membrane and a prefixed breach.
- Infrared thermal imaging indicates the level of moisture content below the membrane. It mainly emphasizes the temperature difference due to the difference in the heat gain between the wet and dry areas.
- Nuclear metering, similar to infrared thermal imaging and capacitance testing, indicates the moisture content rather than the breach location. The apparatus contains radioactive material that interacts with water molecules in case of a breach. It allows the tester to identify its location.
- Low voltage electrical conductance testing uses a simple electric voltage to identify the exact location of the leakage. It tests a nonconductive waterproofing membrane as the test uses a waterproofing membrane as an electric separator. The leakage point completes the circuit showing its exact location.
- High voltage spark testing has a similar methodology to low voltage testing. However, it does not need spraying water to conduct the test. It is preferred over low voltage because of its simplicity and waterless procedures.

- Thermal insulation
It protects the building from heat temperature leading to a more comfortable temperature on the uppermost floors of the building. It is mainly a rigid hardboard made of extruded polystyrene (XPS) (Whittemore, 2007).

- Root barrier
It mainly protects the structure and waterproofing membrane from the damage caused by the plants' roots. The roots are destructive enough to drill through the waterproofing
membrane causing water leakage to the building structure. Therefore, the root barrier has to be checked for the following properties (Cascone, 2019):

- resistance to the chemical solvents produced by the plants' roots
- resilience to the micro-organism within the growing media
- repellent abilities against the plant roots

The typical thickness of the membrane is 4 mm and is implemented using hot-air welding or a chemical solvent. The root barrier and waterproofing layer can be merged into one layer, as many root barriers are made from the bituminous membrane; it depends on the designed system of the green roof. However, a green roof is built on an existing building with an efficient waterproofing system, and a root barrier membrane has to be added (Cascone, 2019).

- Protection layer

It is commonly added on top of the root barrier and water proofing membranes to protect them from loads of the above layer, including the growing media and the plants. Its most important property is its compression pressure resistance to resist loads during the construction and operational phases. The compression resistance is usually higher than 150-kilo pascals. The common materials used are a combination of geotextiles and geogrids or polystyrene, with a minimum thickness of 3 mm. some materials can store water used by the plants during drought (Cascone, 2019).

- Drainage layer

It is essential for the plant and building, as plants require air-water balanced growing media. The drainage layer allows the excess water to evacuate the green roof system while its cavities provide sufficient air. 60% of the drainage layer should be saturated by air. This allows a healthier growing media for the plants. Also, the drainage layer stores an efficient amount of water for drought periods. On the other hand, removing excess water reduces the loads on the building structure and the waterproofing membrane. This process increases the durability of the whole system and prevents problems caused by system failure (Cascone, 2019).
There are two primary groups of drainage layers: granular material and drainage mattes. Each has its characteristics for a good performance and has its pros and cons for its use, as discussed as follows (Cascone, 2019):

- Granular materials: different types of aggregate are used, such as crushed bricks, expanded perlite, clay, or slate. To have an adequate drainage system, the minimum thickness is 6cm and a density of 150 kg/m³. If porous, it can hold some water.

- Drainage matte: these mattes are mainly made of plastic or synthetic materials having a thickness between 2.5-12 cm and an average weight of 20 kg/m². Figure 5 presents a sample product of the drainage matte.

It depends on whether the project uses granular materials or drainage matte. For small-size projects, granular materials can be practical, considering that the roof is flat or has a maximum of five percent slope. Their transportation and installation are considered one of their main limitations. However, for large projects, drainage mattes are preferable. They are easily transported and implemented, especially if made into small-sized panels. The water flow and air cavities are more efficient, allowing for better drainage systems and a healthier environment for plant growth. Their cost and disposal are considered usage drawbacks (Cascone, 2019).

- Filter sheet

Its primary role is separating the drainage system and the growing media. By avoiding the penetration of the soil’s small particles, and plants roots into the drainage matte, the drainage system will perform well and increase the life span of the whole green roof system. There are two types used described as follows (Cascone, 2019):

- granular materials, same as the drainage mattes, require a water permeability higher than 0.3 m/s.

- non-woven geotextile sheets, having a water permeability higher than 0.3 cm/s and water absorbent of 1.5 l/m² and the types are commonly used.

- Growing media

It ensures the establishment and endurance of proper growth of the plants besides its subordinate function as noise and thermal insulation, improving water quality and
rainwater management. The irrigation strategies, vegetation, roof design, and climatic conditions determine the substrate components, thickness, and weight. The intensive green roof of 50-60cm thickness weighs around 600 kg/m² while the intensive one of 8 cm thickness weighs 12-14 kg/m². It is essential to consider the growing materials' physical and chemical properties. Their design failure causes improper growth for the plants and functionality of the drainage system (Cascone, 2019).

The growing media mainly consists of organic and non-organic substrates. Organic materials include peat and compost, while inorganic is pumice, perlite, and crushed stones. It is recommended to increase the percentage of the non-organic ones due to their low weight and density and high porosity that increase the amount of air within the soil and its drainage abilities. Especially on existing buildings where the construction of a green roof is not planned before the construction, it is essential to consider low-weight materials (Cascone, 2019).

- Irrigation system

In arid climate countries, irrigation is essential for the durability of the green roof. Like the conventional landscape, irrigation can be added on the surface of the growing media or beneath it. It is connected to the controller to organize the irrigation scheme. However, in most green roof cases, it is companioned by moisture and rainwater sensors. This modification helps irrigate based on the growing media moisture content and prevents irrigating while raining. The sprinklers or surface or subsurface drippers are some of the standard irrigation systems (Nektarios, 2018). 20 L/m² of water is required for irrigation in dry climate countries. Instead of fresh water for irrigation, grey water can be used after treatment (Mahmoudi et al., 2021). Using grey water can reduce the pressure on the freshwater supply and drainage system.

- plants

Plants are the leading visual indicator for the performance of the green roof. If the plants look healthy and growing, this indicates the overall performance of the green roof. Their types are proportional to the roof load capacity. The roof load capacity controls the weight and depth of the growing media. Consequently, it controls the plant species that can be used (Cascone, 2019). As the depth increase, more types of plants can be used. Mosses and
sedum are suitable for a depth less than or equal to 5cm; grasses, small bulbs, and short perennials can be used for a depth between 5-10cm, and as for 10 – 20 cm, average sized perennials, bulbs, grasses, and annuals are used (Cascone, 2019). Not only the physical properties of the soil, identified in its thickness limits the used plant species. Also, the chemical properties specified in terms of PH-value, salinity, and nutrients can alter the plant types (Cascone, 2019). Not all plants can live within the same level of salinity and PH-value and require the same ratio of nutrients; consequently, a composition of suitable plants can be selected to endure the long-term performance of the green roof.

Also, the site surroundings and its climatic conditions limit the types of plants. Solar radiation, humidity, wind, and rainfall limit the used plant species (Cascone, 2019). For instance, some plants require a shaded area to grow, while others need more solar radiation. The surrounding buildings might shade parts of the roof, causing different patterns of solar radiation, and consequently, different plants composition is to be used.

Maintenance
The frequency and intensity of maintenance mainly depends the type of green roof; intensive green roof requires more frequent and intense maintenance than semi-intensive and extensive ones. the maintenance activities for intensive green roof are similar to the one made for conventional landscape including pruning, mowing, fertilizing and insect and weed prevention. However, in extensive ones, maintenance might occur once or twice annually. Weeding and cleaning the irrigation system are the main maintenance practices (Nektarios, 2018).

2.2.5 Modular Green Roofs
This implementation method mainly uses modular, easily installed, and maintained parts. These modules usually consist of trays, and sometimes mats. The modular system ensures the benefits of green roof technology while overcoming the limitation of the conventional method; modules are known for their simplicity and flexibility during implementation and maintenance. Trays are put beside each other on top of the waterproofing membrane and then filled with soil and plants. This process is shown in Figure 4. Any tray can be easily removed at any point in time for maintenance. At the same time, the mats are already pre-planted and have a thickness of 45 mm, as shown by (Hui & Chan, 2008).
2.6 Case Studies of Green Roof Migration into Countries

This section will study several countries, focusing on their development including green roof technology. A revision of their green roof regulations and associations will be presented. Several countries have adopted green roof technology into their construction market, specialized developed ones. Germany, Canada, Japan, Singapore, and Hong Kong are successful case studies of the migration of this technology (Ismail et al., 2012). Within this research, Germany and Singapore are explicitly studied due to the pioneering stage of Germany in implementing green roof technology and the rapid development of Singapore in adopting it. This comparative study presents both countries' efforts and motives for implementing this technology.
Green roof in Germany

The first emergence of green roof technology in Germany's construction market began in the 1960s. It was intended to reduce energy consumption (Shafique et al., 2018). Germany has progressed its green roof market a lot to the present time. In 1975, Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), an independent non-profit organization, was founded to improve the environment by researching plants and their application. One of its 40 committees researches green roof technology and publishes its guidelines and implementation procedures (Peter, 2005). In the 1980s, the market for the green roof in Germany expanded rapidly, and FLL published its first edition of the German green roof guideline and developed several additions since then (Shafique et al., 2018). The FLL Work is considered a reliable resource for implementing green roof technology worldwide, and its standardization has been developing simultaneously with the development of green roof technology in Germany during the last century (Peter, 2005).

Meanwhile, several unprofitable organizations were established to promote green roof technology within Germany. For instance, Deutscher Dachgärtner Verband E.V. (DDV) focused on raising awareness within the governmental sector. Through meetings and seminars with local authorities, the association has helped convince the authorities to regulate the green roof within the local policies (Appl & Ansel, 2004). In addition, Fachvereinigung Bauwerksbegrünung e. V (FBB) is spreading the green roof knowledge through public relations and raising awareness. The association connects industry stakeholders, including educational institutes, implementors, suppliers, and designers. Also, they promote basic information about green roofs and their members' works through written and visual media and events (FBB, n.d.).

Besides the existence of the different specialized associations, German governmental policies either encourage or demand the implementation of green roof technology, depending on the nature of the implemented policy. Within each municipality, the nature of the official green roof policy is different; however, they fall into two categories; being incentives or regulations (Ngan, 2004). An incentive encourages the citizen in its doing while the regulation demands its implementation. Regulations can burden state citizens
due to the expense of system installation (Zulhabri et al., 2012); however, it fastens the migration of the technology into the construction market (Ngan, 2004). Incentives are financial support, encouraging citizens interested in green roof benefits to installing it (Zulhabri et al., 2012).

There are two types of incentives within Germany that encourage green roof construction; direct financial incentives and indirect ones. Direct financial incentives offer either sharing part of the construction fees or paying a certain amount per the implementation of each meter square of green roof. For instance, Bremen, a state in Germany, subsidizes 25% of the total cost of the green roof with a 1,500-euro ceiling amount. The indirect one reduces some building utilities costs, such as stormwater disposal, in return for implementing green roofs. In 2004, 201 out of the 398 municipalities that responded to the FBB survey split the stormwater fee with the green roof owners (Ngan, 2004).

Some municipalities' development regulations or nature conservation acts might require the implementation of a green roof. According to the nature conservation act, nature lost due to construction activities must be compensated. Green roofs are considered one form of compensation for the lost natural land where the building was built. On the other hand, the building codes within some municipalities include implementing the green roof. Often the regulations are joined with incentives (Ngan, 2004).

Since some municipalities require green roof implementation in Germany, it was essential to question the performance of the implemented green roof. Different rating systems were developed to inspect the performance of the green roof in the long run and whether the green roof design meets the municipality's objectives for encouraging green roof technology (Ngan, 2004). In the 90s, the FLL developed a green roof rating system that questions both the green roof components and their functions. It judges whether the implemented system is valid for ecological compensation. On the other hand, it helps the governments question the implemented system's functionality (Hui, 2010).

Also, the government needs to lead by example by implementing green roofs. States are implementing green roofs on state-owned buildings. North Rhine Westphalia is one
the densest cities in German, with a distribution of 1200 citizens per square kilometer, besides being industrial. The city offers direct financial incentives for the implementation of green roofs (Life, n.d.). One of the initiatives the local authorities of North Rhine Westphalia took is implementing green roofs on public buildings (Mann et al., 2021).

Increasing Public awareness is vital to the cities' green roof transitions. Media coverage helps make the green roof concept more appealing to the public. In Muhleim, the green roof implementation increased to the constant media coverage that usually writes green roof articles. On the other side, competitions encourage the implementation of green roofs in Karlsruhe. The government encourages greening the built environments in this industrial city through local competitions (Ngan, 2004).

Germany's green roof market size is growing by an average of 7 % annually, as presented in Figure 6. More than 66-million-meter square of the green roof was planted from 2002 to 2020. Despite the massive number of installed green roofs, the number is minor compared to the annual construction activity. For instance, in 2020, 7.8 million square meters of roofs were planted out of 100 million flat roofs. This shows many areas for progression within the German construction market. The green market is divided according to the used system type; approximately 84% are extensive green roofs, and the remaining are intensive. However, there is a growing trend towards intensive ones for their usage as gardens. In recent years, the average annual growth for an intensive green roof has been 10.6 %, while 6.7 % for extensive ones (Mann et al., 2021).
Green roof in Singapore

Singapore is a dense urban city that has land scarcity. To realize the size of Singapore, Cairo, the capital of Egypt, has an area of 3095 square kilometers while Singapore has 721.5 square kilometers. As for the population, Singapore has more than 5 million residents, with a density of 8292 per square kilometer. In the 1960s, the government announced its vision of having a city in a garden (Skyrise Greenery, 2017). One of its objectives is the restoration of nature within the built environment. Implementing green roof technology is one of its methods (Npark, 2022).

In the 90s, architects started integrating the green roof concept within several buildings due to its aesthetic appeal (Skyrise Greenery, 2017). In 2009, the government proclaimed its sky rise greenery initiative, Encouraging the implementation of green roofs and walls. One of its principal aspects is the government subsidiary of 50 percent of the implementation cost. This has supported over 200 projects by 2013 (Mithraratne, 2013). in
2018, 155 hectares of green walls and green roofs were implemented (GARDENS IN THE SKY, 2018). One 2030 Singapore sustainable development goal is to reach 200 hectares of green roofs and green walls (Skyrise Greenery, 2017).

Since the skyrise greenery initiative, the government has supported green roof research and standardization. Several constitutional documents and technical publications have been available, discussing the benefits of green roofs, standards, and guidelines for their implementation and maintenance (HWANG & ROSCOE, 2015). For example, National parks boards, formed under the Ministry of National Development of Singapore, have been researching plant types and growing media to ease the implementation of the technology.

Singapore governmental authorities consistently introduce greening policies and monitor their correct implementation. Urban development authority (UDA), a governmental authority, is responsible for integrating greenery into new development sites through guidelines and policies. In 2019, UDA introduced Landscaping for Urban Spaces and High-Rises (LUSH), a set of several initiatives demanding the reintroduction of greenery into the built environment. For example, the Landscape area replacement policy, one of the LUSH initiatives, obligates the greenery area to the new development sites. The minimum required greenery area has to be equivalent to the whole development site. Several remarkable green roof projects constructed in Singapore are discussed in detail in section 2.7.

Besides having green roof guidelines and policies, the government supports green roof awareness campaigns done by the private sector. National Parks Board and the Singapore Green Building Council has supported the implementation of green roof on ten public buses, as presented in Figure 7. It is the first of its kind in Asia. It is considered part of a study investigating the effect of green roofs in improving the vehicle's thermal performance and reducing the fuel used for air conditioning. It also raises public awareness about green roof technology. The three months are determined for the study to check the system's efficiency before expanding its implementation on other buses (Zhang, 2019).
Singapore and Germany have presented successful models for implementing green roof technology nationwide. There are repetitive methods used in both countries that helped in the use expansion of green roofs. These methods are explained as follows:

- Governmental initiatives and regulations for implementing green roofs
- "Leading by example" governmental initiatives
- The use of public awareness campaigns in terms of public projects, use of media, and public competition
- The development of green building rating systems
- The involvement of non-governmental organizations, the research community, and the existence of specialized associations

The existences of the previously mentioned methods are discussed in detail in the context of Egypt in section 3.3.

2.7 Green Roof Case Studies

Different case studies from around the world show the impact of green roofs on both the users and the building itself. The green roof can serve different purposes for each building.
type and segment of users, for example, education, social, medical, and health. Also, these case studies will present different aspects of green roof technology, including the materials used, plantation, and its type.

Educational Sector

Many Educational facilities, such as schools and universities, implement green roofs for educational purposes besides using them as social gathering areas. Within the urban setting, people do not know much about agriculture procedures. A green roof is used for cultivating plants. For instance, in 2005, an extensive green roof was implemented at St. Simon Stock R.C. Elementary School in New York, USA. Half of the roof was planted by native plants, and edible plants in the other half. It is being used as both an educational facility and research. Students were taught how to grow fresh vegetables and maintain the plants, as shown in Figure 8, and some science experiments occurred. Simultaneously, it provides extra social space for the school community. From an environmental aspect, a microclimatic environment was created upon this roof. Bees and butterflies were commonly seen. After its implementation, a massive decrease in the heating bill was noticed. (Case Studies for Green Roofs, n.d.). Also, academic research takes place depending on the nature of the academic faculty.

![Figure 8: Students being taught basic farming skills (Case Studies for Green Roofs, n.d.)](image)

Nanyang Technical University in Singapore has challenged the norm and implemented a sloped green roof to inspire creativity. As an art school, the building encourages uncommon ideas and thoughts through its bold silhouette, as shown in Figure 9. The curvature of the design merged with a sloped green roof distinguishes the
building from its surroundings. Grasses with native plantations are selected to add uniqueness to the building while blending with its surrounding setting. This green roof acts as a social space for all the building users besides cooling the building and gathering rainwater (NTU, 2015). The project emphasizes the abilities of the existing green roof technology to deliver the design motives and objectives while acting as a social space and insulating layer to the building.

Shopping Facilities (Malls)

Within the new navy district, Bratislava, the Capital of Slovakia. A new social center, Navy Mall, was created with several functional purposes in 2021. It was designed to serve as an international bus station, a retail center, and a fresh food market directly connected to the building's green roof. Its green roof was not only used to produce fresh crops. However, it has dedicated areas for picnics and barbeque parties, a children's playground, an exercise zone, and a running track. All these areas were surrounded by dense native plantations, as shown in Figure 9. A social hub was created to serve business district employees, bus station passengers, shopping mall customers, and whole families living within the area (Green Roof of Navy Mall, n.d.).

Healthcare Buildings

Vermont Medical Center has been awarded the Leadership in Energy and Environmental Design (LEED) gold award, with a green roof as one of its environmentally responsible strategies. The green roof at the University of Vermont Medical Center serves as a public area that is used by the hospital staff, patients, and visitors. It has seating that overviews the surrounding mountains. A general look at the roof is shown in Figure 9. The hospital restaurant uses freshly grown vegetables in the roof beds. While it is used as a nutrition-health food learning opportunity for the patients, and one private part of the green roof is also used as a healing garden, it is used privately used by patients for relaxation and self-reflection.

Public buildings

Aspired by the Singapore concept of having a garden city, Jewel Changi Airport has a forest-inspired garden at its center, constructed in 2019 (Jewel Changi Airport, n.d.). As shown in Figure 9, the indoor garden is disturbed among four floors around a 40m height
waterfall. Thousands of plants are used (Jewel Changi Airport, n.d.). It is considered a new concept for airports internationally. They act as a traveling hub, shopping destination, and hotel facilities having a unique indoor garden. Also, it is accessed by both residents and international travelers. It is a unique model for airports, as it merges between the public destination, a mall, and an airport while adding a natural dimension. It also showcases the Singaporean image of being a garden city to the whole world (Jewel Changi Airport, n.d.). This shows the green roof technology’s capabilities in providing a green atmosphere within buildings.

Another creative project that shows how integrating green roof technology can change the urban environment is The High Line in New York. An abandoned elevated railway turned into an urban park using a green roof system. With the help of a local nonprofit organization, friends of the Highline, this railway was not demolished, and announced a competition for its renovation. This has spread awareness and excitement about its renovation plan. With the help of the local authorities and professionals, an urban park was designed and implemented in several phases and well maintained, as shown in Figure 9. The railway tracks were left exposed to connect the existing park with its origins. The project presents how green roof technology can help preserve any place's originals and heritage if designed and implemented correctly (HISTORY, n.d.).

To reduce the urban heat island effect and improve the air quality within Chicago, The City Hall Building had a green roof implemented in 2001. This project used a research site to test different plant types and the technology's environmental benefits (CHICAGO, 2022). It was ideal for comparative research because only half the total roof area is planted (Green Roofs, n.d.). The roof demonstrates five thousand in annual savings from the building utility bills (CHICAGO, 2022). It collects rainwater for irrigation (Green Roofs, n.d.).

PARKROYAL on Pickering, a Singapore hotel, has shown the green roof’s ability to break the limits of the original site greenery. This hotel has double the greenery amount if planted on the site’s land. The design has a greenery podium every four storeys. The high trees and palms visually link the hotel greenery with an adjusted park (PARKROYAL, 2013). This adds a sense of harmony and continuity with the surrounding areas. This project has presented the possibilities green roof technology can fulfill if this technology
is integrated within the whole building, not only on the roofs. It maximizes the potential of greenery and contributes to creating the purposed image of the building.

Moesgaard Museum presents the ability of green roof technology to serve different purposes throughout the year. Figure 10 shows the museum's sloped roof (Moesgaard Museum, 2015). it is used as a multipurpose area. In the summer, the roof is used for picnics, BBQ parties, cycling paths, and even as an outdoor lecture area and a theatre (Moesgaard Museum, 2015) (Moesgaard Museum, n.d.). While in winter, it is famous as an ice-sliding arena. The green roof and its multiuse concept add to the iconic architectural image of the museum; the green roof looks like it merged with the surrounding greenery. The building presents a conceptual migration between nature, history, and culture through the green roof uses and museum artifacts. In addition, the green roof reduces the energy use of the building. Walkways are merged within the roof to provide emergency exits from the building (Moesgaard Museum, 2015).
Figure 9: Green roofs implemented in public projects worldwide

a) Part of the Navy mall green roof (Green Roof of Navy Mall, n.d.)

b) The green roof at the University of Vermont Medical Center (UVM MEDICAL CENTER ONCOLOGY GREEN ROOF, n.d.)

c) The indoor garden within the Jewel Changi Airport, Singapore (Jewel Changi Airport, n.d.)

d) Part of the High Line, New York (HISTORY, n.d.)
Residential projects

The Commons is an implementation of a new residential concept applied in Australia. It mainly presents affordable housing units with shared services while adding many sustainability concepts to the building. One of these shared services is an accessible rooftop with a winter deck and a productive garden (*The Commons*, 2019). As shown in Figure 10, the winter deck is mainly a social area merged with patches of greenery. While the productive garden mainly consists of planters for cultivating edible crops. The roof is attentionally designed to allow for more social opportunity while acting as an insulation layer, rainwater management method, and contribution to reducing the urban heat island effect (*Sustainability*, n.d.). another similar project exists in San Francisco, USA. Drs. Julian & Raye Richardson Apartments serves the homeless within the community. It provides permanent living units with some shared facilities. The roof combines social areas with planters for cultivating edible crops and sedum-green roofs, as shown in Figure 10. The planted areas help capture rainwater and decrease the tension on the city infrastructure (Holmes, 2012). These projects emphasize the Condominium concept of shared services within the building. Providing a green roof as a communal space within Egyptian apartment buildings is questionable. It can help the technology to expand within the market by distributing its implementation cost to all the building residents. However, it might not be accepted by all social classes due to privacy concerns. Therefore, it needs to be tested within the Egyptian context.

Meera Sky Garden House represents the potential gains of green roof technology in Villas. It can improve the residents' quality of life. As shown in Figure 10, each floor has a shaded green roof on top, reducing the roof heat transfer and eventually reducing the use of the cooling system. Besides enhancing the thermal performance of the building, these green roofs are accessible from each floor (SKY GARDEN, n.d.). This enhances the users' experience and connection to nature. Also, in the tropical climate of Singapore, the technology helps manage rainwater and reduces the pressure on the country's infrastructure (SKY GARDEN, n.d.).
2201 Dwight Way complex is a student housing project having a roof farm that produces crops for both luxury restaurants and residents (ROOFTOP FARMING, n.d.). The complex was built in 2016. It is considered the first project that merged communal housing and professional roof farming. Besides providing edible plants, the green roof reduces the energy consumption of the building and provides a social space for the building residents (Garden Village, n.d.).

The previous examples show that green roofs can suit any building type. Designers have to figure out the users' needs that can be fulfilled within the roof area and mold the design to accommodate these needs. The green roof is generally a value added to any building.
Figure 10: Green roofs implemented in different building types projects worldwide

a) The Commons, Australia (*The Commons*, 2019).
b) Drs. Julian & Raye Richardson Apartments (Holmes, 2012)
c) Moesgaard Museum, Denmark (Moesgaard Museum, 2015)
d) City Hall, Chicago (Green Roof, n.d.)
e) Meera Sky Garden House (SKY GARDEN, n.d.)
f) 2201 Dwight Way, California (ROOFTOP FARMING, n.d.)
Chapter 3

Green Roof within the Egyptian Market

3.1 Overview

Considerable interest has occurred in researching the green roof within the last ten years. However, some countries were more interested in the topic than others. The United States has carried out over 20% of the whole publication. On the other hand, Europe has contributed to 37.84% of the total publications of all other continents. Africa is last by 0.91% contribution (Suszkoowicz & Kolasa Wieck, 2019). This shows that much research is required within Egypt to evaluate the potential of green roofs within the Egyptian culture and the country's physical and climatic conditions. This chapter is mainly concerned with reviewing the existing papers about green roof technology in the context of Egypt, presenting their methodology and outcomes, and showing the missing areas for research. On the other hand, it presents the present green roof market in Egypt, including the green roof companies in Egypt, their works and their used green roof technology and its prices, and mega projects that include green roofs within their designs.

3.2 Research on Green Roof Benefits in the Egyptian Context

This section presents all the available research on the benefits of the green roof within the Egyptian context. Social, economic, and environmental benefits are shown separately to show the quality and quantity of research done in each division.

1.3.2 Research on the Social Impact of Green Roof

Research on the social impact of green roofs in Egypt is almost nonexistent. As the green roof market is still beginning, the number of people who experienced a green roof is very few. (Ibrahim, 2018) has questioned 350 residents on their perspective on having a plantation on their roofs. These residents live along the ring road, a freeway within the
periphery of Cairo with much traffic daily. A questionnaire was used to inquire about the existing use of roofs and the residents' perception of the advantages and disadvantages of green roofs. The outcomes showed the number of responses related to the environmental, social and economic benefits of green roofs. The environmental ones ranged the highest, and the social ones ranged second. Eventually, the economic benefits ranged last. The residents expected rooftop usage mainly for storage and bird breeding.

Moreover, some assume that the roof can be used for gathering. 60% believe it is expensive to have plants on the roof (Ibrahim, 2018). The results show the perspective of the residents. However, it does not present grounded social benefits for green roofs within the Egyptian context. This might have been captured if the research targeted people having green roofs or used roofs with planters.

2.3.2 Research on the Economic Impact of Green Roof

Several papers have tested the energy reduction and economic benefits of installing green roofs within the Egyptian context. The standard methodology used a computerized simulation to compare the traditional ways of constructing roofs in Egypt and installing a green roof system instead. They take into consideration the contextual climate and the Egyptian building codes. Several have presented some critical factors that affected the thermal performance of the green roof. Mainly, this section will present both the methodology and results of these papers.

A group of researchers checked the thermal performance of green roofs on a residential building taking the Egyptian context as their case study. They have tested the effect of several factors: building dimensional ratio, soil depth, and soil conductivity. Using a Design Builder program, they checked three prototypes facing north-south with the same area but with a different dimensional ratio of 1:1, 1:1.5, and 1.2. The difference between the three prototypes was not much. However, the prototype has a dimensional ratio of 1:1.5 and performs slightly better. The study revealed that soil conductivity is the most significant factor among the other factors: soil depth and dimensional aspect. The soil conductivity (k) mainly measures the amount of salt in the soil. Also, The paper tests three values for heat conductivity: 0.3, 0.6, and 0.9 W/ (m·k). Results revealed that the lower the conductivity value, the better the performance. Also, the research shows that the thinner the soil is, the better the thermal performance becomes due to the thermal
mass and evapotranspiration. However, it does not provide the best comfortable condition in winter (Kamel et al., 2012). Similar results are presented by (Ragab & Abdelrady, 2020). Both researchers agree on the effect of heat conductivity and soil depth on the performance of green roofs.

In addition, (Kamel et al., 2012) show that the green roof can conduct 15% - 32% savings; 1600 EGY can be saved compared to the traditional method of roof construction and 4600 EGY un-isolated roof (Kamel et al., 2012). These results can be considered outdated as the electrical in Egypt are changing annually within the last couple of years. In 2016, Egypt obtained an International Monetary Fund (IMF) with a conditioned structural reform, including removing energy subsidies. Table 1 presents the Egyptian electricity ministry's last electricity increase for residential buildings ("Price of Electricity" 2020). It shows an inconsistent increase between the segments of consumption rate.

Table 1: A sample of the electricity price change in Egypt ("Price of Electricity" 2020)

<table>
<thead>
<tr>
<th>Consumption rate (KW)</th>
<th>Price for 2020 – 2021 (Egyptian piasters)</th>
<th>Price for 2019 – 2020 (Egyptian piasters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 50</td>
<td>38</td>
<td>30</td>
</tr>
<tr>
<td>51 - 100</td>
<td>48</td>
<td>40</td>
</tr>
<tr>
<td>100 - 200</td>
<td>65</td>
<td>50</td>
</tr>
<tr>
<td>201 - 350</td>
<td>96</td>
<td>82</td>
</tr>
<tr>
<td>351 - 650</td>
<td>128</td>
<td>100</td>
</tr>
<tr>
<td>More than 1000</td>
<td>145</td>
<td>145</td>
</tr>
</tbody>
</table>

The same group of researchers conducted a similar thermal performance study for green walls and roofs, investigating the effect of combining green walls and roofs on three prototypes. Each prototype differs in its number of floors: five, ten, and fifteen. However, the three of them are residential buildings in the same area. The results present an additional saving of 3,972 EGP if a green roof is added to the 15-floor building having green wall installed on all its facades, 5,045 EGP for the 10-floor building, and 4,750 EGP for the 5-floor building (Wahba et al., 2018). This result shows unproportioned results between insulting the green roof and the number of floors.
Other research presents $2,749.96\ USD$ saved annually from a simulated test using the same design builder program. The results show that the green roof does not only reduce the upper floors’ energy consumption. However, it also reduces the temperature on the roof surface. It can help in reducing the heat island effect. The used green roof systems save between 31.61 and 39.74% of energy and reduce air temperature by four Celsius on average. However, the research presented the importance of considering the allocation of the green roof within Egypt for evaluating the green roof system. A comparison was presented between installing a green roof on a school in Aswan, Alexandria, and Cairo governate. The result revealed that the hotter the climatic zone is, the more influential the green roofs are. Aswan, a much hotter climatic zone than Alexandria and Cairo, presented promising outcomes when comparing the results during the operating hours. A temperature difference between the indoor and outdoor area of 4.17 to 4.78 °C was recorded in Aswan compared to a maximum of 3.68 °C and 3.39 °C in Cairo and Alexandria (Ragab & Abdelrady, 2020).

A pilot-scaled green roof was tested to indicate the thermal effect of green roof modules and surrounding areas. A four to five temperature degrees difference was observed through thermal photography. Also, the research results show that the more profound the used soil within the green roof system, the lower the measured temperature at 3 cm below the soil surface, at the center and the bottom of the green roof system compared to the surface pressure (Hussain et al., 2015). This contradicts the previously mentioned research using a computerized simulation as a primary method for their studies. According to (Kamel et al., 2012) and (Ragab & Abdelrady, 2020), the more the soil depth increase, the less efficient the thermal performance of the green roof becomes due to thermal mass. Deeper soil cannot eliminate the accumulated heat that is conducted during the day throughout the short night time (Ragab & Abdelrady, 2020).

The available research in Egypt does not present any documented data about the thermal performance of a building with a green roof. Most of the research, as presented previously, depends on simulation as their primary data source, except for (Hussain et al., 2015), which used actual modules of green roofs for analysis.
3.3.2 Research on the Environmental Impact of Green Roof

(Abd El-Hafeez et al., 2016) explores the adaptability of green roof technology in different climatic conditions within Egypt and their thermal performance. The study considers the construction materials of residential buildings and the climatic condition associated with their location in Egypt. However, the study does not consider the other building types rather than residential ones, and it does not consider the socio-economical aspect of the residents. Not all residents would afford to implement a green roof on their buildings.

3.3 Green Roof Ecosystem in Egypt

The research will judge the Egyptian ecosystem for green roof penetration within the section. It will check the existence of the supporting factors that can help ease and fasten the technology’s penetration. These factors are based on understanding the influences that helped penetrate the green roof into developed countries, specifically Germany and Singapore. Check Section 2.6 for more understanding of the origin of these factors.

- Green roof technology is still being introduced to the Egyptian market. Urban farming in the form of hydroponics systems has been considered an alternative to the green roof system in Egypt. (Gawad, 2014) claims that there is no green roof in Egypt. The only existing ones are soilless urban farms on top of the informal residence. The Egyptian government has launched a green roof initiative within Cairo. The purpose of this initiative is to encourage residents to grow edible plants for fresh food and extra income (FAO Green Roof, n.d.). Recently, some public-private partnerships have implemented green roofs on governmental-owned buildings. Shargara, a non-governmental organization providing greenery in urban areas, implemented a green roof on a public school, as shown in Figure 11. Using a neglected area, the school roof, the project provided an outdoor classroom as part of the green roof design. Several governmental and private institutes contributed to the project’s existence, including the Ministry of education, the ministry of environment, the Swedish Embassy, and
IKEA. Shagara plans to implement seven more green roofs at public schools (Elassar, 2021).

Figure 11: Green roof implemented within an Egyptian public school (Elassar, 2021)

Several well-known companies are trying to initiate a green roof market in Egypt by promoting their work within this field. The following presents some of these companies:

- **Schaduf**: A company founded in 2011 specializing in green walls and hydroponics systems. They have been trying to initiate the green roofs concept within the Egyptian market for several years. Now they have designed and built their first green roof in a Cairo residential project.

Figure 12 presents their initial green roof design versus its actual images (*Schaduf*, n.d.). The company is considered both a green roof designer and an applicator. Sometimes, they use the Smart Garden system or their supplier, Istanbul Teknik. They are mainly using conventional green roofs for their projects.
- **Living block**: An Egyptian green wall and green roof company use the modular system for their green roof projects. It is mainly square-shaped containers made of Grade A reinforced ultraviolet Polypropylene, which can withstand high load capacities up to 200 Kg/m². They designed and installed the green roof of the faculty residency Building at The American University in Cairo, as presented in Figure 13. It is mainly a grass-planted green roof surrounded by gravel at the roof edges.

- **Smart Gardens**: a subsidiary of an Egyptian company, Shira, mainly specializes in water management and irrigation solutions. The company has partnered with an international green roof supplier, ZINCO, to market the concept and sell its products.
in Egypt, however, it offers green roof technology and outdoor furniture and lighting. Their green roof technology is conventional green roof systems (Smart Gardens, n.d.).

As presented, there is only one international supplier for the conventional green roof system and one local supplier for the modular one. It is a minimal variety. However, it fits the introduction phase of green roof technology to the construction market. The number of projects each company worked on is minimal. By comparing the available systems, the modular system shows some limitations; it cannot be used for planting large trees and palms, only fits small shrubs and turf, and does not fit with the large plantation requirement of soil. In comparison, Smart Gardens focuses mainly on the soil insulation and water drainage layer. The company only recommends suitable waterproofing or thermal insulation components for its green roof project consultants and stakeholders.

<table>
<thead>
<tr>
<th>Layers</th>
<th>Extensive Green Roof</th>
<th>Intensive Green Roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter Sheet</td>
<td>Filter Sheet SF&lt;br&gt;Thermally strengthened filter sheet of Polypropylene.</td>
<td>Filter Sheet TG&lt;br&gt;Thermally strengthened, UV-stabilized filter sheet made of 100 % polypropylene.</td>
</tr>
<tr>
<td>Drainage Layer</td>
<td>Flora drain FD 25-E&lt;br&gt;Drainage and water storage element of thermoformed recycled polyolefin.&lt;br&gt;Material: Polyolefin</td>
<td>Flora drain FD 40-E&lt;br&gt;Drainage and water storage element of thermoformed recycled polyolefin. Material: Polyolefin</td>
</tr>
<tr>
<td>Protection Mat</td>
<td>Protection Mat SSM 45&lt;br&gt;High quality recycled fiber mat made of polyester/polypropylene.</td>
<td>Protection Mat ISM 50&lt;br&gt;High-quality, extremely stable fiber mat of polyester/polypropylene, bottom sided fiber impregnation using acrylic compounds.</td>
</tr>
<tr>
<td>Roof Barrier</td>
<td>Root Barrier WSF 40&lt;br&gt;Seamless polyethylene membrane</td>
<td>Root Barrier WSF 40&lt;br&gt;Seamless polyethylene membrane</td>
</tr>
</tbody>
</table>

Table 2: Smart Gardens green roof components for intensive and extensive systems

Besides several green roof companies, many commercial and residential projects include green roof technology within the designs. Table 3 presents the most recent projects with a green roof as part of their design. Several mega residential and commercial ones conclude the technology. However, during the construction phase, the decision of its implementation is made according to the following options:
Green roof technology is not implemented; its concept and proposed design are only used for marketing purposes. For example, Mountain View, a real estate company, has marketed the green roof garden, as shown in Figure 14, within several projects such as New Cairo Hyde Park and the October I-city compound. This render is part of imagining their proposed concept of being surrounded by nature (Hyde Park, n.d.) (I-City Mountain View, n.d.). However, the company delivers its units as a structure with finished façades and requires interior finishing. Therefore, the roof design decision is made by the unit owner.

![Figure 14: The advertised green roof by Mountain View, a Real Estate company](image)

Natural turf is replaced by artificial turf and uses potted plants, or artificial ones replace both the natural turf and plants. These options are used by many private residential and business owners.

The green roof is implemented. For example, Trio compound is mainly selling the concept of having three duplexes within the same building. Each has its garden, which includes a turf area and a pool. Their mockup and delivered phase have a green roof implemented (Trio, n.d.). In addition, the park mall in new Cairo implemented its branded green concept. It was marketed as a shopping concept within a park (Park Mall, n.d.). These projects show that the importance of implementing a natural green
roof comes from its added value to the project, as the green area is one of the company's primary marketing strategies. A green roof was implemented.

Table 3: Proposed residential and commercial projects with green roofs in Egypt

<table>
<thead>
<tr>
<th>PROJECT INFORMATION</th>
<th>MARKETING IMAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloomfields</td>
<td></td>
</tr>
<tr>
<td>- Developer: Tatweer Masr</td>
<td></td>
</tr>
<tr>
<td>- Location: Mostakel City</td>
<td></td>
</tr>
<tr>
<td>- Compound Area: 415 acres</td>
<td></td>
</tr>
<tr>
<td>- Current situation: Under Construction</td>
<td></td>
</tr>
<tr>
<td>- Green roof information: it will be used as the common social area on the residential clusters and increase the aesthetic appeal of the commercial buildings (Bloomfeilds, n.d.).</td>
<td></td>
</tr>
<tr>
<td>Le Ciel Compound</td>
<td></td>
</tr>
<tr>
<td>- Developer: Bedaya</td>
<td></td>
</tr>
<tr>
<td>- Location: 7th district / New Capital</td>
<td></td>
</tr>
<tr>
<td>- Compound Area: 17 FEDDANS</td>
<td></td>
</tr>
<tr>
<td>- Current situation: Under Construction</td>
<td></td>
</tr>
<tr>
<td>- Green roof information: it will be allocated on top of the residential building (Le Ciel, n.d.).</td>
<td></td>
</tr>
<tr>
<td>RHODES COMPOUND</td>
<td></td>
</tr>
<tr>
<td>- Developer: Plaza Gardens Development</td>
<td></td>
</tr>
<tr>
<td>- Location: R7 / New Administrative Capital</td>
<td></td>
</tr>
<tr>
<td>- Compound Area: Up To 100 Acres.</td>
<td></td>
</tr>
<tr>
<td>- Current situation: Under Construction</td>
<td></td>
</tr>
<tr>
<td>- Green roof information: it will be allocated on top on the residential building.</td>
<td></td>
</tr>
</tbody>
</table>
BOARDWALK
- Developer: Atric Developments
- Location: R7 / New Administrative Capital
- Compound Area: 45 Acres
- Current situation: Under Construction
- Green roof information: it will be allocated on top of the residential building. (Boardwalk, n.d.)

THE GATE
- Developer: Abraj Misr
- Location: Heliopolis
- Compound Area: 450000.0 Sqm
- Current situation: not clear
- Green roof information: it will be used as a social and gardening area for the building residents (The Gate, n.d.).

THE PARK MALL
- Developer: Porto Group
- Location: New Cairo
- Compound Area: 45,000 Square Meters
- Current situation: built and operating
- Green roof information: the mall’s ground floor is elevated to accommodate parking below. On both the ground and the first floors, the outdoor area has a cluster of greenery that visitors can enjoy (Park Mall, n.d.).

TRIO GARDENS / THE ANNEX
- Developer: M Squared
- Location: New Cairo
- Compound Area: 35.5 Acres
- Current situation: under construction
- Green roof information: the compound is designed to have three residential units per building where the company deliver a finished green yard for each. One is on the ground, and the others are elevated green roofs (Trio, n.d.).
Dejoya 1 – 2 – 3
- Developer: Taj Misr Development
- Location: R8, The New Administrative Capital,
- Compounds Area:
  Dejoya 1: 23 Acres.
  Dejoya 2: 11 Acres
  Dejoya 3: 33 Fadden
- Current situation: under construction
- Green roof information: the residential buildings' roofs will be used as a social place for the compounds' residents. It will accommodate cafeterias, a gym, outdoor cinemas, yoga and meditation areas, and playgrounds. All are integrated with green clusters (De Joya, n.d.)

Vertical Forest
- Developer: Misr Italia properties
- Location: IL BOSCO – New capital
- General Information:
  Three residential buildings of 30 meters each. One will have serviced apartments by a luxurious hotel, and the other will have branded apartments for the same hotel chain. The three buildings will have intensive plantations surrounding each floor
- Current Situation: Conceptual phase

Magdi Yacoub Global Heart Center
- Owner: Magdy Yacoub
- Location: Cairo
- General information: the hospital has a second-floor outdoor area. This area is considered a popping-out space for the staff and hospital visitors.
- Current Situation: under construction (Heart Center, n.d.)
Living Pedestrian Bridge
- Location: Cairo
- General information: the project is the winning concept of the Rifat Chadirji prize 2020, presented by five Egyptian architects. It is considered an urban park connecting the Nile River's two banks with recreational, commercial, and social zones.
- Current Situation: concept (LIVING PEDESTRIAN BRIDGE, 2021)

Also, Tarsheed, the Egyptian green building rating system, encourages using the green roof as a heat island migration method and heat transfer reduction within the building. Tarsheed considers four types of buildings: residential, commercial, educational, and healthcare. It also considers communities. Both commercial and residential Tarsheed categories consider two points for new and existing buildings. It only requires planting at least 5% of the roof area (Abridged Reference Guide for Tarsheed - Commercial, 2020) (Abridged Reference Guide for Tarsheed - Residential, 2020). In addition, green roof technology lines up with the Egyptian vision of sustainable development goals. One of the key performance indicators is increasing the percentage of green areas per capita in urban areas. The 2030 target is obtaining 3 sqm of greenery per capita. (EGYPT 2030 VISION, n.d.)

3.4 Cost of Green Roof in Egypt

There are very limited research data about the price of green roof technology in Egypt. (Ragab & Abdelrady, 2020) research shows the cost of the green roof implementation for the studied prototype ranges between 29,700 and 32,400 USD. The prototype is mainly a public-school building with five floors and three classrooms within each floor. Each classroom is of an area of 38 m². The total building area is not shown in the study. However, an accurate estimation for green roof construction per meter square
is not calculated as to be a reference for any green roof projects. The researcher provides the price of each material used within the research, as shown in Table 4, but it did not mention a total unit price. However, the prices of some materials are estimated through an online platform of Chinese suppliers, Alibaba, which is too vulnerable to being misleading; these prices might not include the taxes and the shipping cost. There are several available suppliers in Egypt that can supply all the required materials for the green roof.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Unit Cost USD/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement tiles + mortar + sand</td>
<td>6.5 b</td>
</tr>
<tr>
<td>Ordinary concrete (sloped concrete)</td>
<td>7.5 b</td>
</tr>
<tr>
<td>Bitumen layer</td>
<td>11 b</td>
</tr>
<tr>
<td>Expanded polystyrene</td>
<td>14 a</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>30 b</td>
</tr>
<tr>
<td>Gypsum plaster</td>
<td>7 b</td>
</tr>
<tr>
<td>Filter layer</td>
<td>5 a</td>
</tr>
<tr>
<td>Waterproof layer</td>
<td>2 a</td>
</tr>
<tr>
<td>Drainage layer</td>
<td>3 a</td>
</tr>
</tbody>
</table>

*www.alibaba.com, b Arab Contractor Company, Egypt.

Table 4: Cost distribution of green roof according to (Ragab & Abdelrady, 2020)

Therefore, this section compares the prices of exiting green roof technologies, showing the unit price for each component and the estimated total cost for the unit meter of this technology. This cost study can be used as a reference for the green roof implementation in Egypt. However, the price might change based on each project’s requirements and situation. Transportation and labor costs might change according to the project location within Egypt. Some projects might require extra roof preparation before installing the green roof system. It might require waterproofing or thermal insulation membrane modifications if a green roof is to be implemented. It is essential to consider the current Egyptian economic situation. The Egyptian currency fluctuates due to inflation. Prices are continuously changing (Egypt’s Consumer Inflation, 2022). As all the available green roof products are imported, it is essential to consider the steady increase in international shipping prices. Therefore, this study requires continuous revision for its validation.
### Table 5: Prices of the existing green roof technologies in the Egyptian market (based on the researcher's inquiry)

<table>
<thead>
<tr>
<th>Company Name: ZINCO</th>
<th>Extensive green roof</th>
<th>Price (EGP)/m²</th>
<th>Intensive green roof</th>
<th>Price (EGP)/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filter sheet</td>
<td>Filter Sheet SF</td>
<td>25.01</td>
<td>Filter Sheet TG</td>
<td>48.94</td>
</tr>
<tr>
<td>Drainage system</td>
<td>Flora drain FD 25-E</td>
<td>257.38</td>
<td>Flora drain FD 40-E</td>
<td>358.88</td>
</tr>
<tr>
<td>Protection mate</td>
<td>Protection Mat SSM 45</td>
<td>74.31</td>
<td>Protection Mat ISM 50</td>
<td>168.56</td>
</tr>
<tr>
<td>Roof barrier</td>
<td>Root Barrier WSF 40</td>
<td>69.24</td>
<td>Root Barrier WSF 40</td>
<td>69.24</td>
</tr>
<tr>
<td><strong>Total for extensive green roof</strong></td>
<td><strong>426</strong></td>
<td><strong>Total for intensive green roof</strong></td>
<td><strong>645.5</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Company Name: Living Blocks</th>
<th>System description</th>
<th>Price/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modular containers made of Grade A reinforced ultraviolet Polypropylene (supplied with its plants)</td>
<td>1400</td>
<td></td>
</tr>
</tbody>
</table>

Table 5 presents the selling prices for green roof technologies in Egypt according to the existing suppliers. The prices are presented as unit supply per square meter and do not include Egyptian taxes and the implementation or transportation fees.

### 3.5 Existing Green Roof Market Research

There is limited published data about the existing green roof market in Egypt. This makes the market vague for its stakeholders. For the proper penetration of the green roof into the Egyptian construction market, there is a significant need to understand its
different aspects ranging from the available market size and segmentation to the residents' perspective of green roofs. It would help the stakeholders make the right decision in selection the target group, whether business or house owners, and their marketing strategies.

One of the existing green roof companies in Egypt, Sika, studied both the roofing and green roof market in 2017. For more information about the company, it is presented in section 3.3 . The roofing and waterproofing markets are interconnected; no successful green roof project will exist without a proper waterproofing membrane. The research shows that five million square meters are the estimated roofing market in Egypt, mainly dominated by bitumen as water proofing components followed by polyvinylchloride membrane (PVC). Bitumen is used by 93% of the construction market, while the remaining 7% uses PVC.

One crucial aspect is the testing procedures for the waterproofing membrane; The research shows that flooding the roof with water is the primary method for testing the efficiency of the waterproofing membrane. There is a high demand for other water leakage detection systems as many Egyptian buildings suffer from leakage problems. For more understanding of the types of waterproofing membranes and their testing procedures, section 1.2.5 presents a whole study of the advantages and disadvantage of their use.

As for the green roof market, 50 thousand square meters is the estimated market size. This is considered only 10% of the roofing market. The research shows its estimated distribution of the green market; 95% is residential buildings, 3% for plaza decks, 2% for commercial ones, and null for industrial ones. This division shows that the leading segment for a green roof is the residential buildings, with a massive difference from others. Also, the research presented the market distribution among the intensive and extensive systems. A higher potential is estimated for intensive systems than extensive ones; 70% for intensive and 30% for extensive ones.

The community's perspective on green roof technology is a critical aspect of the research. It shows the purposes and worries of the potential clients towards green roof technology. The esthetics aspect of green roofs is the primary motive for their implementation, with an estimate of 40%. The research does not present the remaining
motives. However, it presents two main concerns that interfere with the client's decision: the green roof implementation price and maintenance. 55% of the clients' concerns lay towards the financial aspect of implementing a green roof, followed by 15% for its maintenance.

Also, the research shows the Egyptian government's vision toward roofs agriculture. Since 2015, the government has launched several initiatives for rooftop gardening with the perspective of growing food. The primary purpose of this initiative is to obtain extra income for the residents besides the environmental and aesthetical aspects of having a green roof. The principal systems used are hydroponics. The research assures the dominance of the Egyptian market by roof agriculture in containers rather than the green roof. Also, it ensures that no regulation or building code in Egypt discusses the proper implementation of green roofs. 2.6 presents examples of other countries' different regulations for green roofs.
Chapter 4

Estimation of Green Roof Market in Egypt

4.1 Overview

The chapter builds a foundation for understanding the market size of the green roof in Egypt. It is mainly based on statistical analysis of the latest available data about the Egyptian buildings. Emphasizing on the market size of this technology can help in realizing its potential benefits. These benefits can range from social and economical to environmental ones. In addition, this analytic study can aim different decision-makers within both the construction and green roof in understanding the potential sizes of the green roof technology, if it is implemented nationwide.

The statistical analysis mainly concerns estimating the market size for the green roof in Egypt. It is based on the Egyptian census of 2017, the latest census release by the Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS). The census release is based on specifying the number of buildings in Egypt, their geographical location, their construction properties, and their use (Census - Building (Governorates), 2017). The following are the definition of some terms used in this census and essential for understanding the statistical analysis within this chapter.

The census defines Regular Buildings for housing Purposes as buildings that are built for residential purposes and are segmented as follows (Census - Building (Governorates), 2017):

- House/ Apartment Building; it consists of a floor or more with a maximum of fourteen floors, and each floor may consist of one apartment or more.
- Skyrise Apartment Building; it is mainly more than fourteen-floor buildings.
- Villa with one or more Units; a building includes one Unit or more with a maximum of four floors. It might have a garden and a parking area.
- Chalet; a building having a unit or more with a maximum of 2 floors and most likely built in coastal areas.
- Country House with one or more Units; a building that does not consist of apartments, however, rooms with a maximum of two floors. It is usually built with clay or bricks.

On the other hand, Regular Buildings for Work Purposes are buildings that are constructed for business services, and the following are its sub-segments (Census - Building (Governorates), 2017):

- Work Building with one Unit or more includes governmental buildings, religious buildings, sporting clubs, hospitals, schools, gas stations, theatres, orphanages, prisons, parking buildings, and shops. Within this census, it is disturbed as follows
- Mall; a building consists of several floors that might include commercial or entertaining services such as cafeterias, cinemas, and shops; however, it might consist of residential units or offices such as medical or law offices.
- Boat House; a longshore or sailing boat with fixed landing points. It can be used for residential or work purposes or both.
- Shop or more; a building mainly used as a one-unit shop or more and has no residential units above.
- Public Building; a building or a set of ones specified for public housing purposes. It can consist of more than one residential Unit.

The census defines Makeshift Buildings as tents, burial yards, and stationary, and Nondescription Buildings as buildings still under construction and cannot identify their use (Census - Building (Governorates), 2017).

Another statistical source used within this chapter is Egypt's statistical year of 2021. It will be used to estimate the distribution of Egyptian buildings according to socio-economic categories. It specifies the types of residential units available according to the income of its targeted groups. It divides the residential units into five categories: low, economic, middle, upper-middle, and luxury. An income limit is specified for each
building category (Egypt - Statistical Yearbook, 2021). However, Table 6 presents a general overview of Egyptian society’s categorization according to family income.

Table 6: Egyptian society categorization according to income (Egypt - Statistical Yearbook, 2021)

<table>
<thead>
<tr>
<th>Categories Of Income</th>
<th>Minimum Monthly Income (EGP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above The Middle Income</td>
<td>20,000</td>
</tr>
<tr>
<td>Middle Income</td>
<td>14,000</td>
</tr>
<tr>
<td>Low Income</td>
<td>4,750</td>
</tr>
<tr>
<td>Below Low Income</td>
<td>More than 2,100</td>
</tr>
</tbody>
</table>

As for the methodology, this chapter shows the hierarchy the researcher used to reach the market size for the green roof in Egypt and its segmentation. This is, in general, discussed below in Figure 15: The statistical methodology for reaching the potential market share for green roof technology in Egypt and its segmentation. However, it will be discussed in detail throughout this chapter.

Figure 15: The statistical methodology for reaching the potential market share for green roof technology in Egypt and its segmentation
4.2 Estimation of the Market Size

This section estimates the green roof market share and presents its different segments. For each market segment, the researcher presents the reason for its creation.

1.4.2 Estimation of the Buildings where Green Roof Technology can be implemented (Market Size)

As a first step, the researcher considered the structure of the existing building in Egypt to estimate the market size. As stated in section 2.4, Green roofs added a uniform dead load that the building structure needed to bare. The 2017 census has divided the building structure into six types; concrete ceilings and pillars, prefabricated materials, red bricks, or their alternatives with concrete ceilings or other, bricks or clay, and other materials (Census - Building (Governorates), 2017).

presents the distribution of Egyptian buildings according to their geographical delineation. The researcher specifies buildings with concrete ceilings and pillars. Since these buildings can handle the structural loads associated with green roof technology, this selection highly identifies the market size of green roofs in Egypt; 7,154,312 buildings with concrete ceilings and pillars out of the 14,769,297 ones. This segment presents 67% of the existing buildings in Egypt, as presented in Table 7.

In addition, implementing the green roof should be limited to urban areas, not rural ones. Having this technology in over-crowded urban areas with limited green areas is more reasonable. Check section 2.1 for more information about the green area quantities in urban areas. As shown in Table 9, the number of potential buildings has been reduced to 2,847,401 when considering their location. This presents around 19.279 percent of the existing building in Egypt.
Table 7: Building distribution according to geographic location and construction type
*(Census - Building (Governorates), 2017)*

<table>
<thead>
<tr>
<th>Governorates</th>
<th>Concrete Ceilings and Pillars</th>
<th>Prefabricated Materials</th>
<th>Red Bricks or their Alternatives and Concrete Ceilings</th>
<th>Red Bricks or their Alternatives and other Ceilings</th>
<th>Bricks or Clay</th>
<th>Other</th>
<th>Total building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>451,202</td>
<td>5,495</td>
<td>45,082</td>
<td>149,693</td>
<td>1,708</td>
<td>17,326</td>
<td>670,506</td>
</tr>
<tr>
<td>Kafr Elsheikh</td>
<td>209,315</td>
<td>761</td>
<td>265,162</td>
<td>52,342</td>
<td>21,451</td>
<td>6,618</td>
<td>555,649</td>
</tr>
<tr>
<td>Fayoum</td>
<td>103,638</td>
<td>365</td>
<td>250,233</td>
<td>258,202</td>
<td>23,166</td>
<td>16,568</td>
<td>652,172</td>
</tr>
<tr>
<td>Doumyat</td>
<td>152,460</td>
<td>230</td>
<td>74,560</td>
<td>120,18</td>
<td>901</td>
<td>7033</td>
<td>247,202</td>
</tr>
<tr>
<td>South Sinai</td>
<td>24,282</td>
<td>254</td>
<td>5,580</td>
<td>11,122</td>
<td>3,301</td>
<td>658</td>
<td>45,197</td>
</tr>
<tr>
<td>Bani Souwaif</td>
<td>124,541</td>
<td>216</td>
<td>232,932</td>
<td>176,803</td>
<td>14,803</td>
<td>7,725</td>
<td>557,020</td>
</tr>
<tr>
<td>Kalyobiya</td>
<td>569,721</td>
<td>1,281</td>
<td>122,920</td>
<td>81,324</td>
<td>54,594</td>
<td>13,386</td>
<td>843,226</td>
</tr>
<tr>
<td>Qena</td>
<td>262,579</td>
<td>310</td>
<td>119,207</td>
<td>56,212</td>
<td>103,030</td>
<td>6,613</td>
<td>547,951</td>
</tr>
<tr>
<td>Port-Said</td>
<td>22,802</td>
<td>28</td>
<td>9,377</td>
<td>11,517</td>
<td>14</td>
<td>6,476</td>
<td>50,214</td>
</tr>
<tr>
<td>New Valley</td>
<td>18,328</td>
<td>64</td>
<td>12,041</td>
<td>12,258</td>
<td>18,777</td>
<td>862</td>
<td>62,330</td>
</tr>
<tr>
<td>Menia</td>
<td>195,691</td>
<td>564</td>
<td>480,824</td>
<td>265,969</td>
<td>70,687</td>
<td>12,725</td>
<td>1,026,460</td>
</tr>
<tr>
<td>Monofiya</td>
<td>479,200</td>
<td>660</td>
<td>70,913</td>
<td>71,292</td>
<td>118,480</td>
<td>5,727</td>
<td>746,272</td>
</tr>
<tr>
<td>Al Gharbya</td>
<td>488,056</td>
<td>602</td>
<td>224,501</td>
<td>49,618</td>
<td>32,076</td>
<td>11,997</td>
<td>806,850</td>
</tr>
<tr>
<td>Dakahllya</td>
<td>615,030</td>
<td>1,204</td>
<td>315,421</td>
<td>74,424</td>
<td>56,120</td>
<td>32,454</td>
<td>1,094,653</td>
</tr>
<tr>
<td>Assiut</td>
<td>351,885</td>
<td>331</td>
<td>151,492</td>
<td>110,210</td>
<td>69,310</td>
<td>9,136</td>
<td>692,364</td>
</tr>
<tr>
<td>Alexandria</td>
<td>291,691</td>
<td>1,547</td>
<td>151,838</td>
<td>32,662</td>
<td>1,040</td>
<td>8,858</td>
<td>487,636</td>
</tr>
<tr>
<td>Suez</td>
<td>63,415</td>
<td>254</td>
<td>11,225</td>
<td>13,251</td>
<td>33</td>
<td>3,975</td>
<td>92,153</td>
</tr>
<tr>
<td>Matrouh</td>
<td>71,896</td>
<td>643</td>
<td>66,121</td>
<td>39,854</td>
<td>6,432</td>
<td>2,025</td>
<td>186,971</td>
</tr>
<tr>
<td>Sohag</td>
<td>446,200</td>
<td>274</td>
<td>134,661</td>
<td>109,864</td>
<td>85,322</td>
<td>16,421</td>
<td>792,742</td>
</tr>
<tr>
<td>The Red Sea</td>
<td>41,210</td>
<td>202</td>
<td>10,955</td>
<td>14,003</td>
<td>25</td>
<td>4,794</td>
<td>71,189</td>
</tr>
<tr>
<td>Sharqyea</td>
<td>758,930</td>
<td>1,656</td>
<td>204,421</td>
<td>169,073</td>
<td>154,737</td>
<td>15,315</td>
<td>1,304,132</td>
</tr>
<tr>
<td>Aswan</td>
<td>83,181</td>
<td>343</td>
<td>73,094</td>
<td>65,655</td>
<td>88,785</td>
<td>4,696</td>
<td>315,754</td>
</tr>
<tr>
<td>Ismailia</td>
<td>103,040</td>
<td>411</td>
<td>35,259</td>
<td>73,932</td>
<td>30,644</td>
<td>3,159</td>
<td>246,445</td>
</tr>
<tr>
<td>El-Beheira</td>
<td>477,507</td>
<td>1,203</td>
<td>533,682</td>
<td>114,729</td>
<td>39,903</td>
<td>27,396</td>
<td>1,194,420</td>
</tr>
<tr>
<td>Luxor</td>
<td>104,277</td>
<td>486</td>
<td>32,121</td>
<td>19,910</td>
<td>78,549</td>
<td>3,192</td>
<td>238,535</td>
</tr>
<tr>
<td>Giza</td>
<td>616,022</td>
<td>1,902</td>
<td>350,750</td>
<td>107,649</td>
<td>28,178</td>
<td>19,731</td>
<td>1,124,232</td>
</tr>
<tr>
<td>Total governorates</td>
<td>7,154,312</td>
<td>21,355</td>
<td>4,028,496</td>
<td>2,190,716</td>
<td>1,105,417</td>
<td>269,001</td>
<td>14,769,297</td>
</tr>
</tbody>
</table>
Table 8: Building distribution by type (Census - Building (Governorates), 2017)

<table>
<thead>
<tr>
<th>Location</th>
<th>Fenced and Unused Land</th>
<th>Nondescript Building</th>
<th>Makeshift Buildings</th>
<th>Regular Buildings for Work Purposes</th>
<th>Regular Buildings for Housing Purposes</th>
<th>Total Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>271,209</td>
<td>60,896</td>
<td>107,146</td>
<td>285,998</td>
<td>4,075,399</td>
<td>4,800,648</td>
</tr>
<tr>
<td>Rural</td>
<td>1,144,557</td>
<td>140,406</td>
<td>161,479</td>
<td>546,039</td>
<td>9,391,934</td>
<td>11,384,415</td>
</tr>
<tr>
<td>Total</td>
<td>1,415,766</td>
<td>201,302</td>
<td>268,625</td>
<td>832,037</td>
<td>13,467,333</td>
<td>16,185,063</td>
</tr>
</tbody>
</table>

(14,769,297 without the fenced and unused land)

Table 9: Distribution of the concrete ceilings and pillars building regarding their geographical location (Census - Building (Governorates), 2017)

<table>
<thead>
<tr>
<th>Governorates</th>
<th>Concrete Ceilings and Pillars buildings in urban areas</th>
<th>Concrete Ceilings and Pillars buildings in rural areas</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>451,202</td>
<td>0</td>
<td>451,202</td>
</tr>
<tr>
<td>Kafr Elsheikh</td>
<td>53,712</td>
<td>155,603</td>
<td>209,315</td>
</tr>
<tr>
<td>Fayoum</td>
<td>36,564</td>
<td>67,074</td>
<td>103,638</td>
</tr>
<tr>
<td>Doumyat</td>
<td>54,233</td>
<td>98,227</td>
<td>152,460</td>
</tr>
<tr>
<td>South Sinai</td>
<td>9,794</td>
<td>14,488</td>
<td>24,282</td>
</tr>
<tr>
<td>Bani Souwaif</td>
<td>53,474</td>
<td>71,067</td>
<td>124,541</td>
</tr>
<tr>
<td>Kalyobiya</td>
<td>184,433</td>
<td>385,288</td>
<td>569,721</td>
</tr>
<tr>
<td>Qena</td>
<td>53,395</td>
<td>209,184</td>
<td>262,579</td>
</tr>
<tr>
<td>Port-Said</td>
<td>22,802</td>
<td>0</td>
<td>22,802</td>
</tr>
<tr>
<td>North Sinai</td>
<td>14,261</td>
<td>13,952</td>
<td>28,213</td>
</tr>
<tr>
<td>New Valley</td>
<td>7,857</td>
<td>10,471</td>
<td>18,328</td>
</tr>
<tr>
<td>Menia</td>
<td>77,966</td>
<td>117,725</td>
<td>195,691</td>
</tr>
<tr>
<td>Monofiya</td>
<td>92,786</td>
<td>386,414</td>
<td>479,200</td>
</tr>
<tr>
<td>Al Gharbya</td>
<td>104,736</td>
<td>383,320</td>
<td>488,056</td>
</tr>
<tr>
<td>Dakahlia</td>
<td>158,705</td>
<td>456,325</td>
<td>615,030</td>
</tr>
<tr>
<td>Assiut</td>
<td>105,601</td>
<td>246,284</td>
<td>351,885</td>
</tr>
<tr>
<td>Alexandria</td>
<td>279,385</td>
<td>12,306</td>
<td>291,691</td>
</tr>
<tr>
<td>Suez</td>
<td>63,415</td>
<td>0</td>
<td>63,415</td>
</tr>
<tr>
<td>Matrouh</td>
<td>43,712</td>
<td>28,184</td>
<td>71,896</td>
</tr>
<tr>
<td>Sohag</td>
<td>95,144</td>
<td>351,056</td>
<td>446,200</td>
</tr>
<tr>
<td>The Red Sea</td>
<td>38,801</td>
<td>2,409</td>
<td>41,210</td>
</tr>
<tr>
<td>Sharqeya</td>
<td>173,457</td>
<td>585,473</td>
<td>758,930</td>
</tr>
<tr>
<td>Aswan</td>
<td>45,013</td>
<td>38,168</td>
<td>83,181</td>
</tr>
<tr>
<td>Ismailia</td>
<td>45,752</td>
<td>57,288</td>
<td>103,040</td>
</tr>
<tr>
<td>El-Beheira</td>
<td>92,871</td>
<td>384,636</td>
<td>477,507</td>
</tr>
<tr>
<td>Luxor</td>
<td>54424</td>
<td>49,853</td>
<td>104,277</td>
</tr>
<tr>
<td>Giza</td>
<td>394,223</td>
<td>221,799</td>
<td>616,022</td>
</tr>
<tr>
<td>Total</td>
<td>2,807,718</td>
<td>4,346,594</td>
<td>7,154,312</td>
</tr>
</tbody>
</table>
The building types need to be considered when estimating the market size. 65,274 units do not have a precise usage (non-description buildings), as shown in Table 12. Therefore, the market size will be specified for buildings having work or housing purposes. This selection will decrease the green roof market size from 19.279 to 18.82 percent.

Table 10: Building types having concrete ceilings and pillars structure in urban setting  
(Census - Building (Governorates), 2017)

<table>
<thead>
<tr>
<th>Governorates</th>
<th>Nondescript Building</th>
<th>Makeshift Buildings</th>
<th>Regular Buildings for Work Purposes</th>
<th>Regular Buildings for Housing Purposes</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>5,421</td>
<td>0</td>
<td>29,718</td>
<td>416,063</td>
<td>451,202</td>
</tr>
<tr>
<td>Kafr Elsheikh</td>
<td>537</td>
<td>0</td>
<td>3,191</td>
<td>49,984</td>
<td>53,172</td>
</tr>
<tr>
<td>Fayoum</td>
<td>194</td>
<td>0</td>
<td>1,983</td>
<td>34,387</td>
<td>36,370</td>
</tr>
<tr>
<td>Doumyat</td>
<td>706</td>
<td>0</td>
<td>3,813</td>
<td>49,714</td>
<td>53,527</td>
</tr>
<tr>
<td>South Sinai</td>
<td>476</td>
<td>0</td>
<td>1,998</td>
<td>7,320</td>
<td>9,318</td>
</tr>
<tr>
<td>Bani Souwaf</td>
<td>291</td>
<td>0</td>
<td>2,545</td>
<td>50,638</td>
<td>53,183</td>
</tr>
<tr>
<td>Kalyobiya</td>
<td>1,078</td>
<td>0</td>
<td>9,139</td>
<td>174,216</td>
<td>183,355</td>
</tr>
<tr>
<td>Qena</td>
<td>1,642</td>
<td>0</td>
<td>2,954</td>
<td>48,799</td>
<td>51,753</td>
</tr>
<tr>
<td>Port-Said</td>
<td>282</td>
<td>0</td>
<td>4,148</td>
<td>18,372</td>
<td>22,520</td>
</tr>
<tr>
<td>North Sinai</td>
<td>259</td>
<td>0</td>
<td>2,332</td>
<td>11,670</td>
<td>13,992</td>
</tr>
<tr>
<td>New Valley</td>
<td>94</td>
<td>0</td>
<td>1,249</td>
<td>6,514</td>
<td>7,763</td>
</tr>
<tr>
<td>Menia</td>
<td>521</td>
<td>0</td>
<td>3,362</td>
<td>74,083</td>
<td>77,445</td>
</tr>
<tr>
<td>Monofiya</td>
<td>578</td>
<td>0</td>
<td>4,699</td>
<td>87,509</td>
<td>92,198</td>
</tr>
<tr>
<td>Al Gharbya</td>
<td>377</td>
<td>0</td>
<td>5,479</td>
<td>98,880</td>
<td>104,359</td>
</tr>
<tr>
<td>Dakahlia</td>
<td>1,124</td>
<td>0</td>
<td>6,753</td>
<td>150,828</td>
<td>157,581</td>
</tr>
<tr>
<td>Assiut</td>
<td>385</td>
<td>0</td>
<td>3,959</td>
<td>101,257</td>
<td>105,216</td>
</tr>
<tr>
<td>Alexandria</td>
<td>3,128</td>
<td>0</td>
<td>18,289</td>
<td>257,968</td>
<td>276,257</td>
</tr>
<tr>
<td>Suez</td>
<td>752</td>
<td>0</td>
<td>4,197</td>
<td>58,466</td>
<td>62,663</td>
</tr>
<tr>
<td>Matrouh</td>
<td>1,232</td>
<td>0</td>
<td>3,737</td>
<td>38,743</td>
<td>42,480</td>
</tr>
<tr>
<td>Sohag</td>
<td>340</td>
<td>0</td>
<td>4,621</td>
<td>90,183</td>
<td>94,804</td>
</tr>
<tr>
<td>The Red Sea</td>
<td>1,990</td>
<td>0</td>
<td>4,062</td>
<td>32,749</td>
<td>36,811</td>
</tr>
<tr>
<td>Sharqea</td>
<td>1,301</td>
<td>0</td>
<td>9,695</td>
<td>162,461</td>
<td>172,156</td>
</tr>
<tr>
<td>Aswan</td>
<td>1,585</td>
<td>0</td>
<td>3,642</td>
<td>39,786</td>
<td>43,428</td>
</tr>
<tr>
<td>Ismailia</td>
<td>317</td>
<td>0</td>
<td>2,961</td>
<td>42,474</td>
<td>45,435</td>
</tr>
<tr>
<td>El-Beheira</td>
<td>958</td>
<td>0</td>
<td>6,996</td>
<td>84917</td>
<td>91,913</td>
</tr>
<tr>
<td>Luxor</td>
<td>555</td>
<td>0</td>
<td>3,410</td>
<td>50,459</td>
<td>53,869</td>
</tr>
<tr>
<td>Giza</td>
<td>1,618</td>
<td>0</td>
<td>14,411</td>
<td>378,194</td>
<td>392,605</td>
</tr>
<tr>
<td>Total</td>
<td>27,741</td>
<td>0</td>
<td>163,343</td>
<td>2,616,634</td>
<td>2,779,977</td>
</tr>
</tbody>
</table>
2.4.2 Estimation of the Buildings where the Green Roof could take place

(Market Segmentation)

It is crucial to dip more profound into the buildings’ types to understand the needs of its user from one aspect and investigate their socio-economic from another. Therefore, this section separately studies both the work-type buildings and residential ones.

3.4.2 Work-type Buildings

Table 11 shows the distribution of the existing work building in Egypt. It is distinguished that administrative buildings are the most common, followed by stand-alone shops and public buildings. However, the possibility of implementing green roofs depends on the economic return from implementing the technology and responsible authority as presented as follows:

- Stand-alone Shops are less likely to have green roofs except for energy efficiency and environmental reason. Still, public awareness and consideration for the environment are low to invest in a green roof for environmental reasons. However, if edible crops are planted, the food and beverage sector can take more privilege of the green roof. This investment must be strategically studied to check its rate of return and whether having freshly grown food would add to the property value. Also, it can be used as an extra outdoor area where restaurants can serve its user within.

- Malls are most likely to have a green roof, which can add much business value to the property. Having extra outer spaces matters from the visitors’ point of view. It can attract more visitors, eventually increasing the mall publicity and rental or selling price of its shops and overall value. Also, some retail stores, kiosks, and designated spaces for outer activities can be well integrated into the green roof design. These alternating advantages can fasten the rate of return of the initial green roof investment and its ongoing maintenance cost. In addition, edible crops can be planted and freshly cultivated for restaurants, cafeterias, and fresh food markets, even though the number of malls is minimal compared to the overall market size. Its rooftop area is crucial to be considered. Many mega malls have a larger rooftop area than residential and administrative buildings.
Work building; many building types fall under the umbrella of a public building, disturbed as follows:

- Office buildings are most likely to consider green roofs as they add to the users’ comfort and increase employee retention. Usually, employees require an outdoor recreational area to spend their break time, a social place for celebration, and casual meetings. Even if the building is planned to allocate several office apartments, the green roof can be a shared place among these offices, increasing the offices' value, or a rental venue that can be used upon request.

- Governmental and religious buildings are less likely to have green roofs on top of these buildings unless political parties are keen on solving environmental problems. Even though some governmental administrative buildings could functionally use the green roof as social space, convincing the political parties to implement this technology is difficult. In addition, the government builds many religious buildings, which will face the same problem of getting their acceptance.

- The recreational buildings include sports and fitness clubs and theatres. The green roof can most likely be implemented within the type of building. It can create more social and recreational outdoor areas. The green roof can differentiate and privilege the faculty from others in the same field as it has a unique outdoor atmosphere.

- Healthcare facilities are most likely to include a green roof. Much psychological health is brought to patients by being surrounded by nature or performing agricultural activities. Also, the in-house restaurant can use freshly grown crops, giving the staff and patients a healthier diet.

- Educational buildings, including schools and universities, are most likely to implement a green roof, primarily privately owned. From a business point of view, it increases the schools' publicity and reliability to have more outdoor areas. It can include playground areas and dedicated spaces for physical and recreational activities. It can allow some educational activities and research concerning the environment and agriculture.
- Service facilities include gas stations and parking buildings. Green roofs are less likely to occur on the roofs of these buildings. The government mainly owns parking buildings. Currently, the government's intention for environmental problems is relatively low. Gas station owners, either the government or private owners, will not have any means of returning their initial investment in building a green roof.

- Orphanages and prisons are less likely to have green roof as it is governmental owned. It is not yet been announced that the government intends to have green roofs on governmental buildings yet. Also, the cost of its implementation is high.

- Public buildings are considered temporary resident buildings provided by the government. Its potential for having a green roof is questionable, as it has to be authorized by governmental decision-makers. Therefore, this building type is disregarded.

As explained, not all work-related buildings are likely to have green roofs for different reasons. Table 11 presents the researcher's estimation of each building type that can have a green roof.
Table 11: Distribution of the work-type building in the urban setting (Census - Building (Governorates), 2017)

<table>
<thead>
<tr>
<th>Governorates</th>
<th>Shop or more</th>
<th>Boat House</th>
<th>Mall</th>
<th>Work Building with one Unit or more</th>
<th>Public Building</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>6,461</td>
<td>0</td>
<td>390</td>
<td>20,999</td>
<td>1,868</td>
<td>29,718</td>
</tr>
<tr>
<td>Kafr Elsheikh</td>
<td>912</td>
<td>0</td>
<td>4</td>
<td>2,122</td>
<td>153</td>
<td>3,191</td>
</tr>
<tr>
<td>Fayoum</td>
<td>245</td>
<td>0</td>
<td>20</td>
<td>1,646</td>
<td>72</td>
<td>1,983</td>
</tr>
<tr>
<td>Doumyat</td>
<td>646</td>
<td>0</td>
<td>14</td>
<td>3,017</td>
<td>136</td>
<td>3,813</td>
</tr>
<tr>
<td>South Sinai</td>
<td>381</td>
<td>0</td>
<td>7</td>
<td>1,352</td>
<td>258</td>
<td>1,998</td>
</tr>
<tr>
<td>Bani Souwaif</td>
<td>509</td>
<td>0</td>
<td>10</td>
<td>1,835</td>
<td>191</td>
<td>2,545</td>
</tr>
<tr>
<td>Kalyobiya</td>
<td>1,561</td>
<td>0</td>
<td>130</td>
<td>7069</td>
<td>379</td>
<td>9,139</td>
</tr>
<tr>
<td>Qena</td>
<td>465</td>
<td>0</td>
<td>13</td>
<td>2377</td>
<td>99</td>
<td>2,954</td>
</tr>
<tr>
<td>Port-Said</td>
<td>1,122</td>
<td>0</td>
<td>7</td>
<td>2,882</td>
<td>137</td>
<td>4,148</td>
</tr>
<tr>
<td>North Sinai</td>
<td>315</td>
<td>0</td>
<td>27</td>
<td>1,971</td>
<td>19</td>
<td>2,332</td>
</tr>
<tr>
<td>New Valley</td>
<td>122</td>
<td>not provide</td>
<td>3</td>
<td>1094</td>
<td>30</td>
<td>1,249</td>
</tr>
<tr>
<td>Menia</td>
<td>433</td>
<td>0</td>
<td>26</td>
<td>2,734</td>
<td>169</td>
<td>3,362</td>
</tr>
<tr>
<td>Monofiya</td>
<td>950</td>
<td>0</td>
<td>25</td>
<td>3,469</td>
<td>255</td>
<td>4,699</td>
</tr>
<tr>
<td>Al Gharbya</td>
<td>1,372</td>
<td>0</td>
<td>12</td>
<td>3,861</td>
<td>234</td>
<td>5,479</td>
</tr>
<tr>
<td>Dakahlia</td>
<td>1,408</td>
<td>0</td>
<td>75</td>
<td>4,882</td>
<td>388</td>
<td>6,753</td>
</tr>
<tr>
<td>Assiut</td>
<td>817</td>
<td>0</td>
<td>24</td>
<td>2,778</td>
<td>340</td>
<td>3,959</td>
</tr>
<tr>
<td>Alexandria</td>
<td>5,593</td>
<td>0</td>
<td>69</td>
<td>11,659</td>
<td>968</td>
<td>18,289</td>
</tr>
<tr>
<td>Suez</td>
<td>1,034</td>
<td>not provide</td>
<td>11</td>
<td>2,872</td>
<td>280</td>
<td>4,197</td>
</tr>
<tr>
<td>Matrouh</td>
<td>1,788</td>
<td>0</td>
<td>27</td>
<td>1,705</td>
<td>217</td>
<td>3,737</td>
</tr>
<tr>
<td>Sohag</td>
<td>628</td>
<td>0</td>
<td>19</td>
<td>3,819</td>
<td>155</td>
<td>4,621</td>
</tr>
<tr>
<td>The Red Sea</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Sharqea</td>
<td>1,257</td>
<td>0</td>
<td>77</td>
<td>7,980</td>
<td>381</td>
<td>9,695</td>
</tr>
<tr>
<td>Aswan</td>
<td>1,149</td>
<td>0</td>
<td>43</td>
<td>2,279</td>
<td>171</td>
<td>3,642</td>
</tr>
<tr>
<td>Ismailia</td>
<td>641</td>
<td>0</td>
<td>10</td>
<td>2,117</td>
<td>193</td>
<td>2,961</td>
</tr>
<tr>
<td>El-Beheira</td>
<td>2,390</td>
<td>0</td>
<td>17</td>
<td>4,439</td>
<td>150</td>
<td>6,996</td>
</tr>
<tr>
<td>Luxor</td>
<td>813</td>
<td>not provide</td>
<td>24</td>
<td>2,315</td>
<td>258</td>
<td>3,410</td>
</tr>
<tr>
<td>Giza</td>
<td>2,201</td>
<td>0</td>
<td>408</td>
<td>11,031</td>
<td>771</td>
<td>14,411</td>
</tr>
<tr>
<td>Total</td>
<td>35,215</td>
<td>0</td>
<td>1,492</td>
<td>114,304</td>
<td>8,272</td>
<td>159,283</td>
</tr>
</tbody>
</table>

The percentage of building of most likely to have green roof

<table>
<thead>
<tr>
<th>The percentage of building of most likely to have green roof</th>
<th>5%</th>
<th>0%</th>
<th>80%</th>
<th>70%</th>
<th>0%</th>
<th>-</th>
</tr>
</thead>
</table>

Total estimation of possible building

| Total estimation of possible building | 1,761 | 0 | 1,194 | 80,012 | 0 | 82,967 |
4.4.2 Residential Type Buildings

Table 12 presents the distribution of residential buildings in Egypt in an urban setting. It is distributed among different types of buildings that refer to the socio-economical differences within the Egyptian community and the time occupancy of the residents. It is noticeable that the Country House type can be neglectable as only five units are available. This is realistic as the research concerns building in urban settings. Also, chalet units are considered secondary houses for summer or winter vacations. It is not reasonable at the current time to have a green roof; this technology is still a new concept; it would be more realistic to be considered it for the family’s primary house rather than its secondary one.

When considering the residential buildings and the probability of implementing a green roof, it is important to consider Egyptian society’s social and economic differences. As discussed in section 3.4, green roof implementation is expensive and will not be realistically implemented by all Egyptian communities. For this reason, the researcher used the distribution of the newly built residential units to reference the socio-economical difference within Egyptian society. Table 13 shows the distribution of residential units from 2014 to 2020. Its distribution is according to the income level of its targeted residents. It presents the total for governmental and privately built projects by private owners or private real estate investors. It is presented as follows: low cost, economic, middle, upper middle, and luxury level. 2,284,908 was built, with more than 70% for limited-income residents. As for poor (low-cost buildings), the reported number is minimal as some of these buildings are in slum areas and are not governmental registered. It also shows that the government and private section investors are not investing in this sector.

The research has considered both the low-cost and economic levels as limited-income residents and upper-middle and luxury levels as high-income residents. This estimation easily distinguishes between socio-economical levels and their distribution among the existing residential building. This merging presents the division of residential units as follows:

- 70% are for limited-income residents
- 22% for middle-income residents
- 8% for high-income residents

Table 12: Distribution of residential buildings according to the socio-economical classes within the Egyptian community (Egypt - Statistical Yearbook, 2021)

<table>
<thead>
<tr>
<th>Establishment Year</th>
<th>20/19</th>
<th>19/18</th>
<th>18/17</th>
<th>17/16</th>
<th>16/15</th>
<th>15/14</th>
<th>Total</th>
<th>Total Percent-Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>low-cost level</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>243</td>
<td>468</td>
<td>711</td>
<td>0.031%</td>
</tr>
<tr>
<td>economic level</td>
<td>109,118</td>
<td>751,592</td>
<td>169,754</td>
<td>145,588</td>
<td>154,230</td>
<td>276,335</td>
<td>1,606,617</td>
<td>70%</td>
</tr>
<tr>
<td>middle level</td>
<td>64,393</td>
<td>87,910</td>
<td>118,467</td>
<td>95,961</td>
<td>75,080</td>
<td>59,790</td>
<td>501,601</td>
<td>22%</td>
</tr>
<tr>
<td>upper middle level</td>
<td>129,32</td>
<td>329,811</td>
<td>309,55</td>
<td>252,63</td>
<td>192,99</td>
<td>146,81</td>
<td>136,111</td>
<td>6%</td>
</tr>
<tr>
<td>luxury level</td>
<td>78,06</td>
<td>87,43</td>
<td>69,45</td>
<td>9,788</td>
<td>5,231</td>
<td>1,355</td>
<td>39,868</td>
<td>2%</td>
</tr>
<tr>
<td>Total</td>
<td>2,284,908</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

This estimation mainly considers residential units; however, a residential building might contain one or more units. Realistically, when the socioeconomic level increases, the number of units within a building decrease. Therefore, a slight change in the percentage mentioned above was estimated. Consequently, a distribution of the residential buildings type vs. the residents is estimated as follows:

- High-income residents use 10% of the residential building; 5% are villas with one or more units, and 5% are apartment buildings and skyrise apartment buildings.
- 35% of the residential buildings are middle class and mainly comprise apartment buildings.
- 55% of the residential buildings are for low-income residents and mainly comprise apartment buildings.

As a first batch, the targeted community for implementing the green roof would be mainly high- and medium-income residents. They can offer its implementation cost. As for villa’s residents, it can be considered as a unique private outdoor area. While for apartment buildings, it can be used privately by one of the units’ owners or shared with all the owners to divide its implementation cost. As shown in Error! Reference source not found., 1,152,232 out of 2,616,634 are most likely to implement green roofs, equivalent to 44% of the total residential units.
Table 13: Distribution of the residential building types regarding their demographical location (Census - Building (Governorates), 2017)

### 4.3 Comparison and Analysis

<table>
<thead>
<tr>
<th>Governorates</th>
<th>Country House with one or more Unit</th>
<th>Chalet</th>
<th>Villa with one or more Unit</th>
<th>Skyrise Apartment Building</th>
<th>House/Apartment Building</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
<td>0</td>
<td>57</td>
<td>49,352</td>
<td>1,594</td>
<td>365,060</td>
<td>416,063</td>
</tr>
<tr>
<td>Kafr Elsheikh</td>
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<td>800</td>
<td>91</td>
<td>55</td>
<td>49,038</td>
<td>49,984</td>
</tr>
<tr>
<td>Fayoum</td>
<td>0</td>
<td>2</td>
<td>81</td>
<td>15</td>
<td>34,289</td>
<td>34,387</td>
</tr>
<tr>
<td>Doumyat</td>
<td>0</td>
<td>2647</td>
<td>815</td>
<td>9</td>
<td>46,243</td>
<td>49,714</td>
</tr>
<tr>
<td>South Sinai</td>
<td>0</td>
<td>727</td>
<td>1,243</td>
<td>103</td>
<td>5,247</td>
<td>7,320</td>
</tr>
<tr>
<td>Bani Souwaif</td>
<td>0</td>
<td>1</td>
<td>1,266</td>
<td>101</td>
<td>49,270</td>
<td>50,638</td>
</tr>
<tr>
<td>Kalyobiya</td>
<td>0</td>
<td>3</td>
<td>5,226</td>
<td>185</td>
<td>168,802</td>
<td>174,216</td>
</tr>
<tr>
<td>Qena</td>
<td>0</td>
<td>1</td>
<td>82</td>
<td>2</td>
<td>48,714</td>
<td>48,799</td>
</tr>
<tr>
<td>Port-Said</td>
<td>0</td>
<td>434</td>
<td>441</td>
<td>5</td>
<td>17,492</td>
<td>18,372</td>
</tr>
<tr>
<td>North Sinai</td>
<td>0</td>
<td>0</td>
<td>82</td>
<td>not provided</td>
<td>11,588</td>
<td>11,670</td>
</tr>
<tr>
<td>New Valley</td>
<td>0</td>
<td>0</td>
<td>44</td>
<td>not provided</td>
<td>6,470</td>
<td>6,514</td>
</tr>
<tr>
<td>Menia</td>
<td>0</td>
<td>5</td>
<td>3972</td>
<td>10</td>
<td>70,096</td>
<td>74,083</td>
</tr>
<tr>
<td>Monofiya</td>
<td>5</td>
<td>1208</td>
<td>3</td>
<td>not provided</td>
<td>86,293</td>
<td>87,509</td>
</tr>
<tr>
<td>Al Gharbaya</td>
<td>0</td>
<td>6</td>
<td>209</td>
<td>60</td>
<td>98,605</td>
<td>98,880</td>
</tr>
<tr>
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<td>267</td>
<td>86</td>
<td>150,247</td>
<td>150,828</td>
</tr>
<tr>
<td>Assiut</td>
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<td>3</td>
<td>739</td>
<td>106</td>
<td>100,409</td>
<td>101,257</td>
</tr>
<tr>
<td>Alexandria</td>
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<td>6,344</td>
<td>224,502</td>
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<tr>
<td>Suez</td>
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<td>11,613</td>
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<td>116</td>
<td>43,519</td>
<td>58,466</td>
</tr>
<tr>
<td>Matrouh</td>
<td>0</td>
<td>12,025</td>
<td>3751</td>
<td>7</td>
<td>22,960</td>
<td>38,743</td>
</tr>
<tr>
<td>Sohag</td>
<td>0</td>
<td>2</td>
<td>430</td>
<td>36</td>
<td>89,715</td>
<td>90,183</td>
</tr>
<tr>
<td>The Red Sea</td>
<td>0</td>
<td>285</td>
<td>928</td>
<td>0</td>
<td>31,536</td>
<td>32,749</td>
</tr>
<tr>
<td>Sharqea</td>
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<td>10</td>
<td>3148</td>
<td>173</td>
<td>159,130</td>
<td>162,461</td>
</tr>
<tr>
<td>Aswan</td>
<td>0</td>
<td>4</td>
<td>282</td>
<td>4</td>
<td>39,496</td>
<td>39,786</td>
</tr>
<tr>
<td>Ismailia</td>
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<td>14</td>
<td>568</td>
<td>3</td>
<td>41,889</td>
<td>42,474</td>
</tr>
<tr>
<td>El-Beheira</td>
<td>0</td>
<td>1</td>
<td>581</td>
<td>24</td>
<td>84,311</td>
<td>84917</td>
</tr>
<tr>
<td>Luxor</td>
<td>0</td>
<td>3</td>
<td>192</td>
<td>not provided</td>
<td>50,264</td>
<td>50,459</td>
</tr>
<tr>
<td>Giza</td>
<td>0</td>
<td>313</td>
<td>29610</td>
<td>686</td>
<td>347,585</td>
<td>378,194</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>5</td>
<td>41,826</td>
<td>122,309</td>
<td>9,724</td>
<td>2,442,77</td>
<td>2,616,634</td>
</tr>
</tbody>
</table>

Most likely based to the total number of primary houses:
- 5% of 5
- 0.1% of 0.1
- 39.9% of 39.9

The equivalent most likely to implement green roofs:
- 0% of 0
- 100% of 100
- 26.5% of 26.5
- 42% of 42

Most likely total of building that can be converted into green roof:
- 122,309
- 2575
- 1,027,34
- 1,152,232
Table 17 summarizes the outcomes of the statistical analysis in terms of the type of building and number of buildings more likely to have a green roof. After considering the structural status and geographical location of the buildings and the socio-economical standard of the users, around 8.4% of the total building in Egypt are more likely to implement green roofs. The central portion is for the residential building, estimated at around 93%. The remaining 7% of the potential building is for the work-type building.

Figure 16 presents the previously discussed percentages. However, this statistical analysis of the entire buildings cannot provide the whole perspective about the potential of the green roof market in Egypt or the potential benefits of implementing this technology. Several points need to be considered, presented as follows:

- 45.1% increase in the total number of buildings in Egypt between 2017 and 2006. This increase shows the continuous expansion of the construction market in Egypt, allowing for more opportunities of implementing the green roof system, primarily due to the governmental plan of building newly developed cities like New Capital and New Alamein cities.

- There is a possibility that some building types of users or developers are more interested in implementing green roofs rather than other. In other words, some building types users might appreciate the green roof technology more than others. The motives for implementing green roofs will be investigated in Error! Reference source not found..

- Also, it is essential to understand the market share of green roofs in terms of building size rather than the number of buildings. There is a possibility that some building types might have a larger size compared to others. For instance, some commercial buildings might have a larger built-up area than residential ones. This estimation might allow for more surface area of green roofs to be implemented. This point will be further discussed within this section.
Table 14: Summary for the potential total number of buildings that can implement green roof technology

<table>
<thead>
<tr>
<th>Building type</th>
<th>Number of buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential type: Villas with one or more Unit</td>
<td>122,309</td>
</tr>
<tr>
<td>Skyrise Apartment Building</td>
<td>2575</td>
</tr>
<tr>
<td>House/ Apartment Building</td>
<td>1,027,348</td>
</tr>
<tr>
<td>Total number of potential Residential type</td>
<td>1,152,232</td>
</tr>
<tr>
<td>Total number of residential buildings in Egypt</td>
<td>13,467,333</td>
</tr>
<tr>
<td>Work type: Shop or more</td>
<td>1,761</td>
</tr>
<tr>
<td>Malls</td>
<td>1,194</td>
</tr>
<tr>
<td>Work Building with one Unit or more</td>
<td>80,012</td>
</tr>
<tr>
<td>Total number of potential Work type buildings</td>
<td>82,967</td>
</tr>
<tr>
<td>Total number of work-type buildings in Egypt</td>
<td>832,037</td>
</tr>
<tr>
<td>Total number of potential buildings</td>
<td>1,235,199</td>
</tr>
<tr>
<td>Total number of buildings in Egypt</td>
<td>14,769,297</td>
</tr>
</tbody>
</table>

Figure 16: A summary of the potential market of green roofs in Egypt; the left chart shows the estimated percentage of buildings with more possibility of having a green roof concerning the rest of the Egyptian buildings. The right chart shows the type distribution of the potential building
1.4.3 Empathy on the Relationship between the Building Types and their Green Areas and its Corresponding Correlation with the Green Roof Market

Statistical data about the size of the different Egyptian buildings and their roof areas is almost inexistent. Without the availability of this data, it is not easy to estimate the size of each building due to the difference in location, the associated urban policies, laws, building use, and its service capacity. However, an estimation for the average roof area for each building type is presented according to the following justification. The researcher does not ensure the rightness of the presented data. However, it is a clarification method of the potential market size for green roof technology. The following explains the justification for each building type's estimated average roof area. The researcher estimates that the roof surface area is equivalent to the building surface area.

- Residential buildings

According to research by U.S. Agency for International Development (USAID), the average residential buildings footprints in urban settings in Egypt is 132 square meters. It is based on a questionnaire conducted with a representative sample of households across Egypt. The questionnaire covered 23,460 households distributed among the five main areas of Egypt. These areas are Greater Cairo, Alexandria Governorate, Upper Egypt, Delta, and Suez Canal Governorates. It also considered the slum areas around Greater Cairo. Although the research mentioned was conducted in 2008, it is still the most reliable source. Therefore, the researcher would generalize the previously mentioned average footprint as an average roof area for all types of residential buildings identified by the CAPMAS, Villas, Skyrise Apartment Buildings, and House/ Apartment buildings. It is essential to mention that CAPMAS identifies villas as one or more residential units hosted by a maximum of four floors.

- Work-type buildings

The data about the sizes of work-type buildings, especially in Egypt, is almost absent. The researcher will present all the available information in hand. However, it is not sufficient to present the average sizes of work-type buildings in Egypt. due to
the lack of data; the researcher will not identify a specified average roof area for these building types. However, a range of minimum and maximum average sizes will be discussed. The researcher will have to relate to other countries' data within the same field as it is difficult to estimate an accurate figure with the available data concerning Egypt.

According to the CAPMAS, work buildings include governmental buildings, religious buildings, sporting clubs, hospitals, schools, gas stations, theatres, orphanages, prisons, parking buildings, and shops (Census - Building (Governorates), 2017). The variety within the building type identification makes estimating the buildings’ average area difficult. The only method the researcher based on the roof area estimation refers to another country's data about the sizes of these building types.

According to the U.S. Energy information administration, around half the commercial building in the USA are 5,000 sqft or less (464.5 sqm). 71% are equal to 10,000 sqft or less (929 sqm). These percentages are based on a survey of 6,436 buildings, presenting 5.9 million commercial buildings in the USA. The definition of a commercial building in the USA is equivalent to the CAPMAS identification for the work building. The commercial building considers public buildings, offices, educational, hospitality, and religious ones. the median size is 5400 sqft (501.68 sqm) (CBECS, 2020). The researcher will estimate that 50% more or less of the median size of the commercial buildings in the USA is reasonable to relate to the expected area of a similar building in Egypt. the estimated range for the minimum and maximum average area is 250 sqm to 750 sqm.

Another reference worth mentioning is the study for the average floor area of offices in four districts in Cairo. These districts are the new administrative capital, Sheikh Zayed, six of October city, and New Cairo. The minimum office size is 40.9 allocated in New Cairo. At the same time, the maximum is 212.5 square meters in new Cairo (Galal, 2022). the estimated average size floor area is 126.7 square meters. It is essential to consider the possibility of having a smaller office size outside the capital. However, not all commercial buildings are office-based buildings. Therefore, the previously mentioned average cannot be generalized for all commercial ones.
Retail shops’ estimated average for the roof area is 88.85 square meters. A study is conducted for four districts in Cairo; the new administrative capital, Sheikh Zayed, six of October city, and New Cairo. It shows that the minimum and maximum retail areas are 34.8 and 142.9 square meters. It also identified that the New Administrative Capital is the district with these minimum and maximum retail shop size, among the previously mentioned four districts (Galal, 2022). As these districts are all allocated in Cairo, there is a possibility of smaller shops outside Cairo. On the other hand, the CAPMAS building census identifies the retail building as a unit or more of shops. The researcher believes that having the average floor area of one shop can present the average of several shops in the whole city.

Malls; there is no available statistics about the about the sizes of nationwide malls in Egypt. However, limited data about the sizes of mega malls exists especially the ones in Cairo, the capital of Egypt. Table 15 shows the gross leasable area of various mega Egyptian malls and their construction data. However, this data is not totally reliable for 1,492 malls recorded by CAPMAS (Census - Building (Governorates), 2017). It only ensures that most mall in Egypt are of smaller sizes. In addition, the gross leasable area cannot estimate the roof area of the building (Youssef, 2021). Gross leasable is the total rental area added to the circulation areas within the malls. This Gross leasable area is divided according each mall floor distribution (understanding commercial lease floor areas, 2020). Each floor area is determined according to each mall design.
Table 15: The gross leasable area of different Egyptian malls and their construction data (Youssef, 2021)

<table>
<thead>
<tr>
<th>Mall Name</th>
<th>Gross Leasable Area</th>
<th>Construction Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mall of Arabia, District Mall, Cairo Festival</td>
<td>100,000 – 200,000</td>
<td>2010-2017</td>
</tr>
<tr>
<td>City, Mall of Egypt, City Center Almaza</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katameya Downtown Mall</td>
<td>110,000</td>
<td>2021</td>
</tr>
<tr>
<td>City Stars Mall</td>
<td>150,000</td>
<td>2005</td>
</tr>
<tr>
<td>Cityscape Mall</td>
<td>21,000</td>
<td>2010</td>
</tr>
<tr>
<td>Al-Sirag Mall</td>
<td>14,000</td>
<td>Mid-late 1990s</td>
</tr>
<tr>
<td>Tiba Mall</td>
<td>30,000</td>
<td>Mid-late 1990s</td>
</tr>
<tr>
<td>Geneina Mall</td>
<td>12,000</td>
<td>Mid-late 1990s</td>
</tr>
<tr>
<td>Mall of Tanta</td>
<td>40,000</td>
<td>2019</td>
</tr>
<tr>
<td>Mall of Mansoura</td>
<td>50,000</td>
<td>2021</td>
</tr>
</tbody>
</table>

As more understanding of the malls building type, the researcher referred to other countries’ data. South Africa is the most relevant country, having the required data. Due to its similar geographical location and the equivalent number of malls, it is a reliable reference. South Africa has 1,942 malls (Prinsloo, 2016), while Egypt has 1,492 malls Census - Building (Governorates), 2017). Also, Table 16 shows that the largest six malls in Africa are allocated in Egypt and South Africa (Miaschi, 2018). Based on the south African council of shopping centers (SACSC), 71% of South Africa’s malls have a land area of 0.15 -3.6 ha (1500 sqm – 36000 sqm) (Prinsloo, 2016). The researcher estimates that the average built-up area of malls in Egypt is equivalent to ±50% of the average land area of the mall in south Africa. In other words, the estimated minimum and maximum built-up area of malls in Egypt are equivalent to 9,375 sqm – 28,125 sqm.
Table 16: The ranking of the largest malls in Africa (Miaschi, 2018)

<table>
<thead>
<tr>
<th>Mall Name</th>
<th>Geographic location</th>
<th>Site area (sqm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mall Of Arabia</td>
<td>Egypt</td>
<td>267,000</td>
</tr>
<tr>
<td>Gateway Theatre of Shopping</td>
<td>South Africa</td>
<td>220,000</td>
</tr>
<tr>
<td>Cairo Festival City</td>
<td>Egypt</td>
<td>160,000</td>
</tr>
<tr>
<td>Canal Walk</td>
<td>South Africa</td>
<td>141,000</td>
</tr>
<tr>
<td>Mall of Africa</td>
<td>South Africa</td>
<td>131,000</td>
</tr>
<tr>
<td>Sandton City</td>
<td>South Africa</td>
<td>128,000</td>
</tr>
</tbody>
</table>

In conclusion, Table 17 summarizes the outcome of converting building quantities of the green roof market into areas. It shows, in general, that the retail shops have the minimum estimated unit area, followed by the residential Sector. On the other hand, malls have the largest estimated unit area. As presented in Figure 17, The division of the green roof market is around 17 - 38% for the work-type buildings and 62 - 82% for the residential buildings. The Comparison between the green roof market division in building quantities and sizes shows a more realistic understanding of the green roof market in Egypt. Despite the massive difference between the number of residential and work-type building sectors, their converted areas are more relative. The market size of work-type buildings is around 7% compared to the residential buildings’ quantities. The 7% is equivalent to 17 - 38% if the work-type buildings market size is identified in sizes.

The results presented for the green roof potential market are much higher than those mentioned in the existing literature. Section 3.5 presents fifty-thousand sqm as the estimated market size. While the current results present a range between 183.5 – 245.8 million sqm as the potential area for the green roofs market in Egypt. this shows an average of 4300 times the amount mentioned in the literature. In addition, the green roof market distribution of building types is different. According to the available literature, the estimated distribution of the green market is 95% for residential buildings, 3% for plaza decks, 2% for commercial ones, and null for industrial ones. In comparison, the results show a less segment for the residential buildings of 62 - 82% for the residential buildings. A much higher one is estimated for 17 - 38% of work-type buildings.
Table 17: A summary of the estimated average of the roof area according to the building type

<table>
<thead>
<tr>
<th>Building type</th>
<th>Estimated Average Size (in sqm)</th>
<th>Buildings number</th>
<th>Estimated total average for possible green roof area (sqm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Residential type buildings:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Villas with one or more Unit</td>
<td>132</td>
<td>122,309</td>
<td>16,144,788</td>
</tr>
<tr>
<td>Skyrise Apartment Building</td>
<td>132</td>
<td>2575</td>
<td>339,900</td>
</tr>
<tr>
<td>House/Apartment Building</td>
<td>132</td>
<td>1,027,348</td>
<td>135,609,936</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>1,152,232</td>
<td>152,094,624</td>
</tr>
<tr>
<td><strong>Work type buildings:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shop or more</td>
<td>88.85</td>
<td>1,761</td>
<td>156,464.85</td>
</tr>
<tr>
<td>Malls</td>
<td>9,375 - 28,125</td>
<td>1,194</td>
<td>11,193,750 - 33,581,250</td>
</tr>
<tr>
<td>Work Building</td>
<td>250-750</td>
<td>80,012</td>
<td>20,003,000 - 60,009,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>82,967</td>
<td>31,353,214.85 - 93,746,714.85</td>
</tr>
<tr>
<td><strong>Total for residential and work type buildings</strong></td>
<td></td>
<td></td>
<td>183,447,838.9 - 245,841,338.9</td>
</tr>
</tbody>
</table>

Figure 17: The green roof market division; The left chart presents the division of the green roof market based on the minimum estimation for the work-type buildings, and the right
The chart presents the division of the green roof market based on the maximum estimation for the work-type buildings.

2.4.3 Estimated Benefits of Implementing Green Roofs Nationwide

The benefits of implementing the green roof nationwide are discussed in this section. The social, economic, and environmental benefits will be presented.

Providence of Green Areas

An estimated 183 – 246 million square meters of green areas can be added to the available greenery in Egypt if the green roof technology is implemented on 100% of the estimated potential area. This greenery can help improve the lifestyle and general health of residents in urban areas. Green roofs can subsidize the conservation of green areas, allowing their accessibility tangibly. These green areas are within the user's reach as they are allocated on the roof of their residential unit or workplace. Many social advantages of green roofs are difficult to measure. It requires a collection of qualitative data that is addressed in Error! Reference source not found..

Energy Consumption Analysis

As presented in section 2.3.2, the green roof can improve the energy performance of the associated building. It improves the insulation of the building. Eventually, a temperature decrease is acquired within the upper floors, an estimated average of four Celsius across Egypt (Ragab & Abdelrady, 2020). The following estimates the potential energy reduction if the green roof technology is implemented nationally.

The research estimates that a green roof will reduce the energy the air conditioning unit uses on the building's upper floor. This energy reduction would occur within the summer (June - to the end of August). This unit operates twice a day to reach the thermal comfort temperature for the users. Each time the Air conditioning operates for an hour. The building with implemented green roof would have a temperature higher than conventional by 4 Celsius (5.4 Fahrenheit). Equation 1 is used to calculate the required energy consumption for An AC unit:
Equation 1: The power an air conditioner requires to reduce the indoor temperature for a given amount of Temperature degrees (Understanding EER Rating, n.d.)

\[
\text{Power} = \frac{\text{British Thermal Unit (BTU)}}{\text{Energy Efficiency Rating (EER)}}
\]

- The energy efficiency rating (EER) measures the efficiency of any AC. The higher the value, the more the Air conditioning performance is. Most ACs systems implement in the building sector in Egypt have an average of 2.9-3.2. however, the Egyptian regulation is changing recently. Since June 2020, the minimum allowed EER has been 3.81 (El-Dallal & Youssef, 2022).

- The British thermal unit (BTU) determines the energy required to heat a pound of water by one Fahrenheit. This value is usually used to determine the amount of power the AC needs to reduce the air temperature by a given value (Stanfield, 2021). Equation 2 presents its calculation method where a change in temperature is 5 Fahrenheit as traditional houses would require more energy to reduce these degrees compared to the green roof one. Cubic Feet Per Minute (CFM) determines the amount of time that requires the AC to change the whole air completely in each space. Equation 3 shows its calculation method, where it mainly depends on the volume of the space and the time needed to change its whole air. The area is estimated to be 13985 cu ft (132 sqm) as the estimated average of the residential buildings. 1.4.3 shows the origin of this area estimation. The time required to change the space air is determined by building's use. Residential buildings require 4-10 minutes to change their air capacity (CFM, n.d.). The estimated time is ten minutes as the maximum within the recommended range.

\[
\text{BTU / hour} = \Delta \text{temperature change (Fahrenheit)} \times \text{CFM (cubic feet/minutes)} \times 1.08
\]

Equation 2: The British thermal unit (BTU) per hour (Stanfield, 2021)

\[
\text{CFM} = \text{the volume of the space/time needed to change the whole space air}
\]

Equation 3: CFM calculation (CFM, n.d.)
By manipulating in Equation 1, 4.24 kW is the difference in power needed by the AC within the two scenarios of the traditional and green roof daily. 121 Egyptian pounds (3.96 $) would be saved monthly per building, considering that 0.94 Egyptian piaster is the Average Cost of KW in Egypt (Home Electricity Prices, 2020). If only one AC unit is considered for each potential building, a minimum of 5.2 million kW can be saved monthly. This amount of electricity will correspond to 4.98 $ million in monthly electricity savings.

Carbon Sequestration Analysis

As explained in section 3.2.3, one square meter of a green roof can eliminate a range of 0.313 – 1.88 kg CO2 annually (Shafique et al., 2020). More realistically, the conversion of green roofs in Egypt would happen progressively. Table 18 shows the estimated elimination of atmospheric CO2, based on 20%, 50%, and 100% conversion of green roofs in Egypt. If half of the potential area for green roof in Egypt is implemented, 28 – 231 million kilograms of carbon dioxide can be eliminated from the atmosphere annually. It might be a remarkable quantity. However, compared to the total amount of carbon dioxide emission in Egypt, it is insignificant. According to the World Bank, the estimated total amount of CO2 emission in Egypt was 249,370 kilo-tons in 2019 (CO2 Emissions - Egypt, n.d.).

Table 18: The estimated elimination of carbon dioxide (CO2) based on the conversion percent of green roof technology in Egypt

<table>
<thead>
<tr>
<th>Percentage of the green roof implemented in Egypt</th>
<th>Estimated potential green roof area (sqm)</th>
<th>Estimated eliminated CO2 (Kg CO2 annually)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 %</td>
<td>36,689,568 – 49,168,268</td>
<td>11,483,834 – 92,436,343</td>
</tr>
<tr>
<td>50 %</td>
<td>91,723,919 – 122,920,669</td>
<td>28,709,586 – 231,090,859</td>
</tr>
</tbody>
</table>
Chapter 5

Egyptian Green Roof Projects Analysis

5.1 Overview

This chapter presents on-ground analysis of the green roof market in Egypt. Qualitative data collection and interpretation are conducted to close the gap between academic research and on-ground reality and get real data about the market. Due to the limited number of implemented green roofs in Egypt, qualitative analysis was selected as a practical approach. It can allow the gathering of comprehensive data about the green roof Egyptian market and understanding each project and its circumstances and challenges during the design, construction, and operations phase.

Interviews with stakeholders within the green roof market in Egypt will be conducted, including green roof owners, technology suppliers, and waterproofing applicators. It can allow the gathering of comprehensive data about the green roof Egyptian market and an understanding of each project and its circumstances and challenges during the design, construction, and operations phase. The research will question the following:

- the clients' motives for conducting the projects
- the challenges faced during different project phases
- the interview perspective about the future of green roof technology in Egypt, including its expansion factors and obstacles

The main selection criterion is the person's involvement in the green roof market in Egypt. There are three main categories of participants described as follows:

- planted roof owner or user; whether a green roof owner or someone just having some plantation of the roof
owner or employee of a green roof company; this category includes designers, construction, and maintenance engineers
- waterproofing companies; including the technical team and salesman

The interpretation of this raw data can present a reliable reference for stakeholders within the Egyptian market. They can rely on previous experiences within the same construction market and the same climatic conditions. It can reduce repetitive mistakes and allow for more expansion of green roof technology within the Egyptian market. Also, it can help clients understand the opportunities and challenges the existing green roof technology.

5.2 Interviews Methodologies

The section describes the research method for conducting and analyzing the interviews. The methodology of this qualitative research is divided into three main stages described as follows:

Data Inputs: Egyptian green roof projects are analyzed through limited interviews with all associated stakeholders. A general overview is presented, followed by a detailed analysis of its design, contraction, and operational phases. Green roof designers, contractors, and maintenance engineers are asked about their whole experience, decisions, and challenges during the design, construction, and operational phases. Users are asked about their motives for green roof construction, their experience during the design and construction phase, and typical uses of green roofs.

Data Processing: each project interview's outcome is analyzed separately to understand its main circumstances; including the client motives and project challenges. These challenges are characterized according to their occurrence within the projects phases whether it is a design, construction, or maintenance challenge. This can present a full case study that can be used a reference for future projects.

Data Outputs: the main ideas, discussed during the interviews, are categorized separately for a clear perspective of its content. Each category presents a main idea about a Egyptian market or summaries the common challenges and behavior patterns throughout different projects.
1.5.2 Interview Questions

The following shows the list of interview question for each participants category. Collecting data from different category of interviewee would present different perspectives about the difficulty within the green roof market. it will assist with forming a full understanding of the reality of the market.

Interview Questions for Green Roof Owners
- Motives
  Did you plan to have the roof planted when purchasing the house?
  Why did you buy a penthouse rather than a ground-floor apartment with a garden?
  What encouraged you to have a roof planted instead of having paved?
  Why did you have natural plants instead of artificial ones?
  Did you have any concerns about its construction?
  How did you get to know the green roof company?

- General Information
  How long did it take to be constructed?
  Did you face any problems during the construction phase?
  When has this roof been constructed? How long has this green roof been constructed?
  How much did you pay for it?
  Who are its frequent users?
  What types of activities do you do on it? How often do you use it?
  What do you like or dislike about it?
  After using it for a while, what would you like to change? Why?

- Environmental Concerns
  Have you noticed any birds or insects on the roof?

- Maintenance Satisfaction
  Are you satisfied with its maintenance?
  Do you have any challenges after its implementation, such as water leakage?
Do you notice any changes in your electrical or water costs after its implementation?

Interview Questions for Green Roof Supplier and Applicator

- Industry Inquires
  
  How long have you been in this industry?
  
  What are your services?
  
  How many roofs have you contributed to their implementation?
  
  Has the industry been evolving over the last couple of years?
  
  What are your expectations for this industry in the upcoming years?
  
  What motivated you to get into this market in Egypt?
  
  Do you think the green roof market is well-established or still growing?
  
  What are the main challenges facing expanding the green roof market in Egypt?

- General Information about a Green Roof Project
  
  When and where is it built?
  
  How large is the project?
  
  What is your role in it?
  
  Who is responsible for the design and construction?
  
  What is the persona of its clients?
  
  When did you come on board with the project?

- Technical inquiries
  
  Which green roof system did you use?
  
  Did you install the waterproofing membrane? How did you check its durability?
  
  How did you calculate the roof loads?
  
  What challenges did you have during design and installation?
  
  What soil combination did you use?
  
  What types of plants is being cultivated? Are there any specific criteria for choosing them? Are there edible plants?

- Maintenance inquiry
  
  Who provides green roof maintenance?
  
  How often does the green roof get maintained?
  
  What type of problems did the maintenance team face? How did they resolve it?
- Investigating the property value difference before and after having a green roof
  
  How much do you think a property value changes after implementing a green roof?  
  Have you been involved in any trading process of a property with a green roof?

Interview Questions for Waterproofing Implementor

- How long have you been in this industry?  
- What are your services?  
- How many green roofs have you worked on? Can you classify their types (podiums or roofs)?  
- Can you classify their projects and their type (residential, commercial, hospitality)?  
- Can you specify a location for the expansion?  
- What type of waterproofing method do you advise? What criteria do you use for identifying a suitable waterproofing method for a green roof project? What is the client in taking on this?  
- What waterproofing test do you recommend? Do you think it's efficient?  
- What are your expectations for this industry in the upcoming years?  
- What motivated you to get into this market in Egypt?  
- Do you think the green roof market is well-established or still growing?  
- What are the main challenges facing expanding the green roof market in Egypt?

5.3 Interviews Summaries

This section discusses each project, the researcher inquired about. It summaries the main points presented, within each green roof project, throughout the interviews.

1.5.3 Sodic East Green Roof

Below are the general data about the project and its associated interviewees and shows the project after completion.
General Information

- Designer and implementor: Schaduf
- Green roof system provider: ZINCO provided by their local supplier, Smart Gardens
- Area: 160 – 180 m²
- Location: Penthouse, Sodic East compound, New Cairo.
- Status: completed and operating since 2022
- Maintenance plan: two visits per month.

![Sodic East green roof after completion](image)

**Figure 18: Sodic East green roof after completion**

Below presents a list of the main points being highlighted from the interviews

**The future of the green roof market in Egypt**

According to the green roof division manager at Schaduf, there is a demand for green roof technology in Egypt. This demand is not based on environmental awareness of the green roof; however, it results from the migration of international architecture into the Egyptian one. There is a possibility that the demand will rapidly accelerate within the upcoming years.

**The clients and projects classifications**

Schaduf receives green roof requests from both private owners and businesses. However, some clients require a less sophisticated green roof system. They ask for only providing perforated pipes for drainage, filter sheet, and soil, which the company refuses to provide, backed up with the company's beliefs regarding the importance of each component of the green roof system. They believe that even if there is a need for cost reduction, no system component can be neglected. Also, they had many small-scale projects where the clients’
request plantation for some roof planters, which the company accepts, conditionally using the green roof system. However, their only implemented green roof is the Sodic East project. Other Contract has already been signed for implementing large-scale planters on a mall roof.

Challenges within the Egyptian market: prices of the green roof technology
Schaduf design and construct projects using drainage matte systems provided by ZINCO, a German-based company, and Istanbul Teknik, a Turkish-based company. The company relies on two systems due to the difference in their prices. ZINCO is much more expensive than the Istanbul Teknik. As the Egyptian currency devaluates, the green roof system is getting much more expensive and there is a need the less-expensive products. Therefore, Schaduf partnered with Istanbul Teknik and even tried to do their local product.

Challenges within the Egyptian market: the instability of the economic situation within Egypt
Egyptian Import challenges and inflation is leading to a decline in the green roof market. According to the green roof manager division, it is difficult to import green roof components, and the inflation is making the system more expensive. These reasons have motivated the company to design and build the system locally.

Green roof implementation motivation: privacy concerns and confidence in the green roof contractor as motives for having a green roof
A green roof owner, living in Sodic East compound in New Cairo, preferred having a penthouse due to privacy concerns. A roof garden allows for more privacy than a conventional garden on the ground floor. Therefore, a penthouse with a roof was selected rather than a ground-floor unit. The owner's first intention for the roof design is to have green walls. However, Schaduf proposed having a green roof; turf coverage, and planters, beside the green walls, which the clients accepted. Even though the client was unaware of the green roof concept, she was open to considering new ideas and perspectives out of his confidence in the green roof company
Design enhancement: proper zoning that considers both the plants' needs and the users' requirements

Some turf is struggling due to the placement of some furniture pieces. A study of the furniture placement is required for the correct functionality of the design.

The green roof system used for the sodic east green roof project
the following is the order of the green roof system starting from the roof structure

- Waterproofing membrane, bituminous membrane
- Sloped concrete slab
- Roof barrier
- Drainage matte
- Filter sheet (with a sub-surface irrigation system for turf areas)
- Especially made lightweight growing media (having the irrigating system on top within planters)
- The selected Plantation

As for the soil, the mix depends on the project location and condition. These factors affect the soil moisture retention and components' weight. Sun exposure and humidity specify the moisture retention of the growing media and the irrigation scenario. If the roof is exposed to much sun exposure, a high-water retention soil is required to irrigate the soil several times a day. On the other hand, high humidity requires less water retention soil and less irrigation. The structure building

The following presents the implementor criteria, starting from the most important one, for choosing the plants; however, the company believes that all types of plants can be added to the roof, backed by the existence of the root barrier layer.

- The plants' solar exposure requirements, whether it stands direct or indirect sunlight or prefers indoor or outdoor environment.
- The plants' water requirements
- The client's reference of plants
Design problems: the lack of experience in calculating the loads' capacities of the roof
As the green roof implementation is still new to the construction market in Egypt, having a green roof was not part of the initial roof design. Figuring out its load capacity was a hassle for the roof owner. As the client mentioned, misleading information has been communicated from both the implementor and the compound developer. The compound developer could not communicate a clear load capacity for the roof. On the other hand, the implementor had changed the system loads several times due to changes within the system design. These continuous changes increased the client's worries about the green roof implementation and the implementor's doubts about the roof loads' capabilities. A construction engineer was recruited to calculate the roof load capacity and communicate it to the implementor.

Implementation problems: lack of reliable waterproofing reliability tests
A flood test was used to check the reliability of the waterproofing membrane. The implementor believes in its inefficiency in inspecting the water leakage. Forty-eight hours of flood testing will not ensure the roof's performance over a long period of time. For waterproofing performance insurance, the applicator requires a bituminous anti-root membrane and a sloped concrete layer with chemical waterproofing additives. The client addressed her concerns about the durability of the waterproofing system and mentioned that they might be weak points within the system that have not been revealed yet.

Maintenance concerns: heavy-weighted equipment is to be questioned
Bringing up heavy equipment can be a hassle for maintaining the turf on a green roof. The client should have this equipment stored within the house for the smoothness of the maintenance project. For the east sodic project, the client bought her turf-cutting machine for the maintenance team.

Maintenance concerns: uncertainty about maintaining long-term performance problems.
The maintenance engineer has addressed some concerns about maintaining the system in the long run. Having the green roof layers on top of each other requires destruction to
reach middle-level layers like the drainage matter or filter sheet. For example, if the sub-surface irrigating pipes have been blocked, it would be a hassle to clear them up. It might require destroying a part of the turf to search for and resolve the blockage.

2.5.3 Sika Egypt For Construction Chemicals

The future of green roofs in Egypt

New cities and mega projects, like the new capital city, helps in creating opportunities for green roof technology. Latest technologies are implemented in these cities. Their designers got exposed to the international architecture trends and eventually changed the construction methods, mentioned the Technical and Specification Head.

The clients and projects classifications

Sika Egypt has not implemented any green roof projects in Egypt. However, they implemented several anti-rooted membranes. The head of technical and specification in Sika mentioned that they have implemented waterproofing for many green roof systems. She emphasized allocating green roof systems on podiums rather than buildings roofs. Many projects were located within the residential and governmental districts of New Capital City. Projects include residential and commercial ones.

Challenges within the Egyptian market: prices of construction materials are increasing in general

According to the Head of Technical and Specification, promoting green roof technology into the construction market right now is difficult. As the construction materials are imported, the Egyptian economy suffers from inflation, so promoting an extra cost for implementing green roofs is unacceptable. Sika usually implements a third-party green roof system internationally. However, the company Egyptian entity has no plan for promoting the green roof system.

Design recommendation: the criteria for selecting a waterproofing membrane for a green roof system

The waterproofing layer is selected according to its durability to be submerged in water, its capability to handle the weight of the soil, and its resistance to the plants' roofs. The membrane classification has to match the green roof conditions, or the failure may occur
at any time. Sika's team usually checks the types of green roof plants and soil depth before recommending a waterproofing membrane. The plantation can change the selection of the membrane. If plants of shallow roots system are used, the team can ignore the anti-rooted criteria. These roots will not cause any damage to the waterproofing membrane. Also, the soil depth classifies the weight constraint of the waterproofing materials. as the depth increase, the total weight of the soil increase; accordingly, the selection of a robust membrane that can handle this weight is required.

However, the building structure can restrict the choice of a waterproofing system, whether a liquid is applied or a membrane. Some structures might require liquid-applied ones due to their easiness of application. In general, the liquid applied is preferable for green roofs. As the liquid applied is more durable. However, it is based on the client's budget for the waterproofing, as the liquid-applied ones are more expensive. Sika had PVC, Polyurea, and bituminous membranes applied for the green roof projects.

Implementation problems: the unreliability of the waterproofing tests
The waterproofing applicators use the flood test to check the quality of their work in Egypt. however, it is not practical to test the efficiency of the waterproofing membrane. There is a need for having alternative testing method especially for green roof projects as the roof is continuously confronting water.
5.4 The faculty residency Building at The American University in Cairo (AUC)

Figure 19: AUC faculty residency green roof

General Information
- Green roof system provider and applicator: Living Blocks
- Location: the AUC faculty residence building.
- Status: completed and operating.
- Maintenance plan: one visit per month.

Below presents a list of the main points being highlighted from the interviews

The Future of green roofs in Egypt

The co-founder of living blocks company mentioned that the future of green roofs in Egypt is unclear; the technology is still considered a luxury product and has not originated from environmental awareness. He believes environmental education and awareness are vital to expanding green roof technology in Egypt.

Challenges within the Egyptian market: the need to educate the construction ecosystem about the benefits of green roofs in urban settings.

Expanding green technology within the construction market is impossible without focusing on the environmental education of the designers. They need to understand the benefits of integrating greenery in urban settings. On the other hand, the Living Blocks co-founder mentioned that removing greenery is one of the cost-reduction strategies
applied in many Egyptian projects. There is a need to increase the whole construction ecosystem's awareness about the benefits of urban greenery.

Challenges within the Egyptian market: the need to consider green roofs technology in the design stage
A green roof is not usually considered within the design phase. However, after implementation. This eventually makes its implementation a burden. If it is part of the building design, its cost would be partially equivalent to standard roof finishes. Instead of paying for roof tiles, the green roof system would be implemented.

The clients' motives and projects classifications
Living Blocks had only implemented four projects during the company's nine years of business. One is a roof of a private villa, and two are implemented on top of two immersed underground water tanks in residential compounds owned by Sodic and Saudi developments. The last is AUC faculty residency Building.

Private owners usually fear the implementation of green roof technology. They are commonly worried about water leakage problems in the building. On the other hand, companies are more interested in green roof technology, derived from having a green initiative, maintaining a certain company image, or achieving their Corporate social responsibility (CSR).

As for the AUC faculty building, the university is seeking the Leadership in Energy and Environmental Design (LEED) certification. This reason has motivated them to implement the green roof technology. The LEED certification requires that at least 50% of the building roof to be green, which the university has implemented.

Pros and cons of the living blocks - green roof system
The locality of their system; the Living Blocks system is locally produced in Egypt. This is considered an edge within the market, as there is difficulty in importing any goods right now in Egypt.
Limitation of the soil depth and the used plants; the system has a 12 cm depth limit that only allows the healthy growth of grass, groundcovers, and short shrubs with shallow roots. However, it cannot maintain deeper soil or bigger plants.

Inflexibility and rigidity; the living block system cannot fulfill any curvature within the design. The system has a fixed square geometry that cannot be molded to fulfill curved designs or rounded edges.

The company preferability of irrigation systems; living blocks have tried both the root drippers and the sprinklers. However, they prefer the latter as drippers get blocked by time, and sprinklers are hassle-free.

The system enclosure vs. the unnecessity of adding extra waterproofing membrane; as the plants grow with the system's enclosure, the system can be easily removed to maintain the lower components. Also, as mentioned by the company co-founder, there is no need to ensure the proper functionality of the waterproofing membrane. However, within the AUC project, leakage within the waterproofing membrane occurred after the green roof system was installed.

The ability for the system installation on any finishing condition; the living blocks system can be implemented whether it is a retrofit project or still under construction. It can be added to roof tiles or directly on the waterproofing membrane. Before installing the roof system, the company ensures the roof slope is adequate for the drainage system to operate correctly.

The ease of access for lower roof components for maintenance; as the plants are growing within the enclosure of the system, The system can be easily removed and reinstalled to maintain the lower components of the roof, such as the waterproofing membrane.

The witnessed benefits of the AUC residency building green roof
Only social benefits are witnessed within the AUC green roof, while economic and environmental benefits are not. As mentioned by the sustainability office manager of AUC, some tenants preferred living within this building to others due to the existence of the green roof. They enjoy some valuable time on the roof. On the other hand, no change was noticed in the building's electricity bill after implementing the green roof.
Challenges within the construction market: the reliability of waterproofing membrane
One of the construction problems that has not been witnessed during the construction phase is the existence of leakage within the waterproofing membrane. The problem has been observed after the building operation and construction of the green roof. Consequently, part of the green roof has been removed to maintain the green roof system.

Maintenance challenges: the need for a specialized maintenance team
The university tried maintaining the green roof with its own staff. However, lots of problems occurred, leading to the inquiry for maintenance service from the applicator. These problems include blockage of the drainage system of the green roof and the building, water leakage to the roof components, and unhealthy-looking grass.

Design improvement: Green roof plant selection and consideration for the Egyptian Climate
The AUC university architect emphasizes selecting plants that fit the Egyptian climate. The turf used in the university building requires much water and maintenance. Therefore, plants with fewer water requirements are preferred.

5.5 Analysis and Conclusion
Different main categories of information are observed by analyzing the data from the interviews. Each category is analyzed differently to understand its full potential. In addition,

Category one: the market for the green roofs in Egypt
SWAT analysis would identify the different pillars within the green roof market in the Egyptian context. These pillars include the market strength and weaknesses and present the real Egyptian construction market opportunities and threats. Despite the limited number of conducted interviews, valuable data about the market was observed. The outcome of the SWAT analysis, shown in Figure 20, can be used to develop a strategic plan for different stakeholders. The analysis can leverage the strengths and opportunities while addressing the weaknesses and threats.
<table>
<thead>
<tr>
<th>Market strength</th>
<th>Market weakness</th>
</tr>
</thead>
<tbody>
<tr>
<td>- the existence of different green roof systems</td>
<td>- the expensiveness of the green roof technology</td>
</tr>
<tr>
<td>- the existence of trust between the green roof</td>
<td>- lack of experience throughout different project</td>
</tr>
<tr>
<td>suppliers and clients</td>
<td>phases</td>
</tr>
<tr>
<td>- the applicators reliability on the use of the</td>
<td></td>
</tr>
<tr>
<td>specialized technology for the green roof projects</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Market opportunities</th>
<th>Market threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>- The development of new cities in Egypt</td>
<td>- the preference of planters rather than green roof</td>
</tr>
<tr>
<td>- the demand for the technology due to the</td>
<td>- illeracy of the construction market about the</td>
</tr>
<tr>
<td>migration of international architectural concept</td>
<td>benefits of green roof especially the environmental</td>
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<td>into the Egyptian one</td>
<td>ones</td>
</tr>
<tr>
<td></td>
<td>- the instability of the economic situation</td>
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<td></td>
<td>within Egypt</td>
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<td></td>
<td>- prices of construction materials are increasing in</td>
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<td></td>
<td>general and greenery are reduced within projects for</td>
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<td></td>
<td>cost reduction</td>
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<td></td>
<td>- the need for using reliable water proofing membranes</td>
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<td></td>
<td>and eligible performance tests</td>
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</tbody>
</table>

Figure 20: SWAT Analysis of the green roof market in Egypt

Category two: the clients’ motives

The following are considered the main motives driving private owners or the business sector to implement green roof technology:

- Preference of having a roof garden rather than a conventional garden due to Privacy concerns
- The client's confidence towards the applicator's professionalism
- Obtaining a green building certification
- Companies derive from having a green initiative, maintaining a specific company image, or achieving their Corporate social responsibility (CSR).
Category three: challenges throughout the project phases.

Table 19 summarizes the main challenges that have been crystallized during the interviews. These challenges are mainly centralized around the lack of experience within different project phases and the need for advancement with the waterproofing application.

Table 19: Challenges faced during different phases of a green roof project

<table>
<thead>
<tr>
<th>Project phase</th>
<th>List of challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design challenges</td>
<td>- The lack of experience in calculating the loads' capacities of the roof</td>
</tr>
<tr>
<td></td>
<td>- Communication difficulties between different project stakeholders</td>
</tr>
<tr>
<td>Construction challenges</td>
<td>- the reliability of waterproofing membrane</td>
</tr>
<tr>
<td></td>
<td>- Lack of reliable waterproofing reliability tests</td>
</tr>
<tr>
<td></td>
<td>- The need for proper slope for the drainage system</td>
</tr>
<tr>
<td>Maintenance challenges</td>
<td>- the need for a specialized maintenance team</td>
</tr>
<tr>
<td></td>
<td>- heavy-weighted equipment is to be questioned for a green roof project</td>
</tr>
<tr>
<td></td>
<td>- Uncertainty about maintaining long-term performance problems.</td>
</tr>
</tbody>
</table>

Category four: suggested design improvement.

The following is a list of the suggested design improvement different project stakeholders have mentioned

- Proper zoning that considers both the plants' needs and the users’ requirements
- green roof plant selection and consideration for the Egyptian climate
- the consideration of edible plants
Chapter 6

Conclusions and Recommendations

6.1 Conclusion

The lack of information represents an obstacle to any technology penetration into a new construction market; a data variety about the green roof in the Egyptian context is presented. Therefore, this study can help decision-makers, including investors, property developers, and properties owners, in generating their opinions and decisions about the green roof implementation in Egypt. The following summarizes the outcome of the study:

- Around 8.4% of the total building in Egypt can implement green roofs according to their structural and demographical location, building type, and the socioeconomic level of their users. The central portion is for the residential building, with an estimate of around 93%. However, the remaining 7% of the potential building is for the work-type building.

- The total estimated green roof area is between 183.4 – 245.8 million square meters. If the total potential area for the green roofs in Egypt is implemented, a range of 28 – 231 thousand kilograms of carbon dioxide can be eliminated from the atmosphere up to 462 million Kg CO₂. 121 Egyptian pounds would be saved monthly per building.

- A green roof is considered an emerging technology within the construction market of Egypt. There is a noticeable demand within several mega commercial and residential projects for green roof technology. However, many projects do not implement the technology during construction due to expense reduction or technical obstacles.

- Many challenges face the applicators during different project phases due to the lack of expertise and the unreliability about the roof waterproofing system.

- A lot of cooperating work is needed from the government and the private sector for the rapid and stable implementation of the green roof nationwide. There is a need to use policies, building codes, and incentives beside educating the public about the sustainability, in general, and the green roof benefits.
- The available research considering green roof technology in Egypt is limited. There is 
a need to have an intensive understanding of the expected benefits of green roofs 
socially, financially, and environmentally.

6.2 Limitations

The following are considered the major limitations that restricted the presented study:

Limited and outdated statistics about the construction market in Egypt
In this research, the statistical analysis is based on a national building Census report of 2017. This census is the latest produced by the responsible Egyptian authority, CAPMAS. It is considered outdated data and needs to be revised. However, this is the most reliable data the researcher can obtain. Also, there is a need to expand the variety of data collected. The researcher had to estimate some information due to their inexistence in the available statistics. For instance, the building census report does not provide data about the sizes of the buildings. For more understanding of the potential market of green roofs in Egypt, the researcher had to estimate their average sizes based on other countries' information. In addition, the report divides the Egyptian building into two main segments: residential and work-type. There is a need to categorize their sub-segments; according to their exact use or the socio-economical standard of their users. For example, It does not classify the exact building type of the work-type building, whether it is an educational or commercial, or medical facility. Also, it does not divide the residential buildings according to their existence in gated or ungated communities.

The conduction of a limited number of interviews with both clients and green roof suppliers
The number of interviews conducted within this research is limited for several reasons. First and most importantly, the number of implemented green roof projects and green roof companies is minimal. Also, some green roof managers refuse to conduct interviews or provide any information about the green roof market in Egypt. it is based on their beliefs about the privacy of these data and their inability to share it even for research purposes.
6.3 Recommendation

Many stakeholders within the green roof market in Egypt or acting as influencing partners need to cooperate in fastening the technology's maturity and expansion. Based on the research findings and discussions, the following are the primary recommendations for each stakeholder.

Recommendations for green roof ecosystem

- Detailed, up-to-date information about the construction market in Egypt is required. This data helps researchers and policymakers understand the present conditions and predict the future of Egypt's green roof market. Validating this study's findings, especially the market size estimation, is mainly based on the existence of the missing data.

- The need for incentives and regulations concerning the green roof concept; linking policies to a financial incentive can soften the transformation process of flat used roofs into social gathering spaces surrounded by vegetation.

- Development of education and awareness programs is needed to increase the public knowledge and real estate ecosystem about the benefits of green roofs.

- Implementing the green roof on public buildings as a national initiative; being an initiative lead will help promote green roof technology nationwide. This will encourage local authorities and real estate developers to consider the green roof in new and retrofit projects.

- The creation of standardized guidelines and governmental followed up for its correct implementation and use. This technology must be implemented correctly to fit our building loads and insulation property. This would help reduce failure on any green roof project, especially within its introduction phase to the Egyptian market. Consequently, it will help expand within the construction market and protect the public.

- Public-private partnership requires the government to encourage the work of NGOs and the private sector within the green roof market. Easing and facilitating their work can help motivate the use of green roofs and benefit from them.
- Applicators must test and use other waterproofing performance tests besides the flooding test. It can be in creating a correct foundation for the safe implementation of the green roof technology.
- Suppliers should increase the awareness of both the engineering community and applicators about the different types of waterproofing and their performance tests that fit the green roof technology.
- One in all warranties is needed to strength the trust of the clients in the green roof applicator. One in all warranty allow the client to obtain his warranty from one entity, green roof applicator for the work done through the green roof project, either if it is done by the green roof applicator or subcontractor.
- Clients have to be flexible and understand that the green roof market is still emerging in Egypt. The projects might require much effort and time to coordinate between all stakeholders, including the designers, construction engineers, green roof suppliers, waterproofing suppliers, applicators, and general project contractors. Also, the existing of some difficulties within all the project phases, from design to construction and maintenance
- Providing academic education for young designers about sustainable development and green roofs. There is a need to build a whole generation that believes in sustainable development and the benefit of urban greenery and green roofs
- There is a need to consider other cost reduction methods rather than eliminating the greenery within the projects. Also, reals estate developers should consider green roofs beside the conventional landscape. Green roof technology can add value to their projects if adequately marketed.

6.4 Recommendation for Further Research

the following are the research gaps confronted during the development of this study and require further investigation

Validation of this study’s findings

There is a need to validate the finding of this study by carrying out more detailed surveys and interviews with broader applicants and users of green roofs. Also, other
resources for estimating the market size of Egypt need to be considered to ensure the correctness of the presented estimation.

Checking the performance of green roof materials in a hot arid climate
Many green roof products available within the Egyptian market are manufactured overseas in different climates than the Egyptian ones. Checking their durability and performance is mandatory for the technology growth within Egypt. Examining these products based on our climatic conditions can prevent unforeseen problems during the product performing period.

Checking the potential of each governorate in respect to its need for green roof technology
A deeper investigation regarding the potential of each Egyptian is recommended; each governorate has its specialized culture and needs beside its own climate condition. Some might be more overcrowded or have fewer green areas than others. These variations can show different potentials for each governorate in implementing green roof.

Performing a life cycle analysis for the green roof in Egypt and considering the use of recycled materials
A life cycle analysis needs to be conducted to fully understand the environmental aspect of the green roofs in Egypt. Many of the green roof products available in Egypt are manufactured internationally and require international transportation, questioning the capabilities of plants during their whole lifetime to overcome the produced pollutants of the manufacturing, and transportation is required. Also, understanding the system disposal options and its recycling possibilities is highly required.

Testing the performance of different plants within a hot arid climate
Different plant species need to be tested within the climatic context of Egypt using the green roof system. Their performance needs to be evaluated and recorded to help designers select suitable species for their projects. Designers need a reference for the plants' performance to ensure their projects' durability. The selection of plants has to consider both the plants' requirements and the aesthetic assets of the plants. Plants species used in conventional landscape projects in Egypt might not fit with the green roof system.
Therefore, intensive experimentation is required to understand the fitness of different species with the green roof technology and climatic conditions.
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