GREEN ROOFTOP SYSTEMS: A SOUTH AFRICAN PERSPECTIVE

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29 February 2016

Study Leader: Dr. B.G. Zulch

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APPROVAL

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Petronella Hendrina Labuschagne

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ABSTRACT

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The purpose of this study is to determine the outcome of green rooftop systems in South Africa. Cities in South Africa are expanding with new developments. With development and expansion comes the increase in pollutants, undesirable living conditions and challenges to overcome. Rooftop gardens are not getting the recognition for the value of it to the environment, the citizens, the industry and the buildings as such in South Africa. This is due to lack of knowledge and innovation. Green rooftop systems is a relatively new concept in South Africa.

The study used a literature review followed by field notes and 68 questionnaires received back from contractors, quantity surveyors, engineers, architects and citizens of Johannesburg.

The respondents do not have experience regarding the construction of green rooftop systems, and thus indicates why professional members of the construction industry do not recommend the development thereof. This further indicates that there is a lack of knowledge in the industry regarding the construction of green rooftop systems and the benefits that accompanies green rooftop systems. Despite the lack of knowledge in the industry, the materials needed to construct green rooftop systems are available in South Africa.

Johannesburg seems to benefit most from improved air quality and better insulated buildings. Other benefits also includes job creation, aesthetics, eliminating the heat island effect, stormwater management and economic growth. Respondents do not utilise existing green areas due to crime and unsafeness and green rooftop systems provide a secure and safe green area. Green areas also provide health benefits such as promotion of health, reducing stress, depression and anxiety.

Drainage and structural integrity seems to be important factors that may limit the development of green rooftop systems due to the financial impact. Incentives seem to be the best way to encourage the development of green rooftop systems according to the respondents. Therefore finance is a concern for the development of green rooftop systems in South Africa; however, there is a demand for it as the respondents are willing to pay more rent for property with green areas. Property value thus increases with the development of green rooftop systems and absorbs the financial impact thereof.

There are different types of green rooftop systems with different cost implications and according to the respondents, the semi-intensive green rooftop system will be feasible for South African circumstances. The field notes presented that the few existing green rooftop systems in Johannesburg are semi-intensive green rooftop systems. Green rooftop systems may conserve indigenous plant species and create habitats.

In conclusion, Johannesburg will benefit from green rooftop systems, despite the capital cost. The professionals in the construction industry do not have experience in the construction of green rooftop systems and have a lack of knowledge thereof, thus do not recommend the development of green rooftop systems to developers.

The lack of knowledge regarding the construction of green rooftop systems and the benefits provided by green rooftop systems should be addressed, not only the construction industry, but also to the public.

Keywords: Green rooftop systems in South Africa, the South African perspective of green rooftop systems, how to construct green rooftop systems, effects of green rooftop systems

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CHAPTER 1: INTRODUCTION TO STUDY

1.1 TITLE

Green Rooftop Systems: A South African Perspective

1.2 INTRODUCTION

Cities in South Africa are expanding with new developments. At the forefront of expansion is Johannesburg. Between 2001 and 2011, the population of Johannesburg increased by an average of 121 000 annually. An average number of 43 000 new homes were built every year over the same period. Johannesburg is forecasted to double in size by 2040 (City of Johannesburg, 2012: 2). With development and expansion comes an increase in pollutants (Momberg & Grant, 2008: Online). A concern in the twenty first century is the continual decrease in air quality and the change of air composition. South Africa is a developing country, which means that there are obstacles to overcome. South Africa needs to learn with regards to controlling pollutants. Countries such as China, Japan and the USA have had years of experience overcoming the problem of over populated cities and the pollution that comes with it. South Africa should learn from the mistakes of experienced countries and the solutions that these countries have implemented in correcting mistakes. A possible solution that may be implemented to combat increasing air pollution and unhealthy environment is the use of rooftop gardens (Miller, 2015: Online). Rooftop gardens are used in Asia where population density is high, yet as South African cities expand and become denser, South Africa seems to fail to consider such a solution. There seems to be advantages to the rooftop gardens established in the major cities of first world countries, such as Singapore and Hong Kong, which have many rooftop Gardens.

People in cities are drawn to green areas such as parks and botanical gardens. As more cities develop, fewer green areas are available for citizens to escape to. Rooftop gardens might help eliminate the complete loss of green areas in cities (Peck & Kuhn, 2003: 3).

1.3 THE RATIONALE

The quality of air and living conditions in major cities in South Africa are continually declining as the cities, including Johannesburg, Cape Town and Durban, grow relentlessly. Together with undesirable air quality, other challenges are present in growing cities (Rode & Burdett, 2011: 454). This problem needs to be addressed. The expansion of cities requires land for development and comes at the expense of the natural environment, which is often removed completely. The primary impact continued development has, is the resultant decrease in plant density which in turn decreases the quantity of clean air being produced.

If plants are replaced by creating rooftop gardens, it might help solve air quality and environmental issues (Grové, 2012: Online). It is necessary to research the validity of rooftop gardens in South Africa and the effect that green rooftop systems may have on the environment and living standard of people by considering both the advantages and disadvantages.

1.4 PROBLEM STATEMENT

Rooftop gardens are not getting the recognition for the positive contribution of it to the environment, the citizens, the industry and the buildings as such in South Africa. This is due to a lack of knowledge and innovation.

1.5 HYPOTHESES

- Green rooftop systems is a new concept in South Africa and underdeveloped.
- South Africa, and specifically Johannesburg, will benefit from the development of green rooftop systems, despite water shortage problems.
- There is a demand for green rooftop systems in South Africa and the developments thereof will be feasible.
- Green rooftop systems will contribute to the conservation indigenous plant species.

1.6 THEORETICAL FRAMEWORK AND OBJECTIVE

Air quality is decreasing as air pollution increases. Global warming is a reality and the human population is expanding. As a developing country, South Africa has not yet faced severe problems associated with its population; however, the South African population is increasing and the quality of living conditions seems to worsen (Momberg & Grant, 2008: Online). It is not only poor air quality, but also the lack of natural elements and ineffective buildings that add to undesirable living conditions.

There is a significant difference between flora and climates of South Africa compared globally. Therefore, rooftop gardens may require a different approach in South Africa than in other countries. In South Africa, certain materials might or might not be available. South Africa might have certain skills or a lack thereof. Green rooftop systems might be a new concept for South Africans and a lack of knowledge goes with it. It is necessary to determine the outcome of green rooftop systems in South Africa. The future of the planet is the main objective and South Africa might contribute to sustaining nature and desirable conditions to live in.

Green rooftop systems might have a specific effect in cities of South Africa (Van Niekerk, Greenstone & Hickman, 2011: 5).

Developers are at the forefront of developing cities. Building regulations are used to regulate and implement a certain standard of development. If both the developer and building regulations incorporate rooftop systems with new developments, it might give the implementation of green rooftop systems a boost (Kazmierczak & Carter, 2010: 3).

The aim of this study is to determine how familiar or unfamiliar green rooftop systems are amongst the professionals in the construction industry as well as the citizens in South Africa and why. Thus determining the level of knowledge in the construction industry, the reason of the level of knowledge and how to increase the level of knowledge in order to increase the development of green rooftop systems in South Africa. Another objective is to determine if there is a demand for green rooftop systems and what advantages and disadvantages provided by the presence of green rooftop systems will have an impact on cities in South Africa. An additional aim to the research is to determine the approach that needs to be taken in South Africa when constructing a green rooftop system.

1.7 RESEARCH METHODOLOGY

The research methodology was as follows:

1.7.1 Literary review: Journals, books, articles, internet and observations were used to gather sufficient information regarding rooftop gardens.

1.7.2 Empirical study: Data were collected via questionnaires and field notes.

1.8 CHAPTER OUTLAY

The chapter outlay is as follows:

CHAPTER 2: INTRODUCTION TO GREEN ROOFTOP SYSTEMS

This chapter introduces green rooftop systems and includes the history of green rooftops and types of green rooftop systems as well as a comparison of the types of green rooftop systems.

CHAPTER 3: THE EFFECT OF GREEN ROOFTOPS IN CITIES

Green rooftops in cities have various effects; advantages, disadvantages and changes in the city's behaviour. The aim of this chapter is to determine all the possible effects of green rooftop systems in cities.

CHAPTER 4: CONSTRUCTING GREEN ROOFTOPS

The aim of this chapter is to determine how to construct a green rooftop system and whether South Africa has the materials available that is needed to construct green rooftop systems.

CHAPTER 5: PLANTS SUITABLE FOR GREEN ROOFS IN SOUTH AFRICA

Plants that are indigenous to South Africa and that have the specific characteristics needed to survive on rooftops are listed.

CHAPTER 6: RESEARCH DESIGN AND METHODOLOGY

Chapter 6 reviews the research design and methodology used to gather data for this study.

CHAPTER 7: FIELD NOTES – ROOFS IN JOHANNESBURG

A field notes to analyse existing green rooftop systems in Johannesburg was conducted and is reported on in this chapter.

CHAPTER 8: EMPIRICAL STUDY IN GREEN ROOFTOP SYSTEMS IN SOUTH AFRICA

This chapter provides an analysis of the empirical data. Respondents' opinions are interpreted in order to determine the perspectives of South African citizens regarding green rooftop systems and to test the literature review.

CHAPTER 9: CONCLUSION AND RECOMMENDATIONS

In this chapter conclusions are being drawn regarding the findings of the literary and empirical study. From the conclusions, recommendations are given.

Chapter 2 presents an introduction to green rooftop systems.

CHAPTER 2: INTRODUCTION TO GREEN ROOFTOP GARDENS

2.1 INTRODUCTION

Green rooftops have been part of construction for thousands of years. The history of green rooftops will be discussed in this chapter as well as three different types of green rooftop systems and the elements that form part of a green rooftop system.

2.2 THE HISTORY OF GREEN ROOFTOP GARDENS

The human population is growing rapidly on a global basis. Along with this rapid growth, cities are expanding and becoming urbanized. More than 50% of the world's population lives in cities. This rapid urbanization is putting pressure on sewage, fresh water supplies, the air quality, and living environment. Carbon emissions are increasing and it is putting more pressure on ecosystems (Rode & Burdett, 2011: 454). According to Petkova, Jack, Volavka-Close and Kinney (2013: Online), Africa currently has the fastest growing population in the world. It is projected that the population of Africa will be more than double in 2050 than it is in 2010. Petkova *et al.* (2013: Online) predict that nearly 60% of Africa's population may soon be living in cities, compared to less than 40% in 2011. According to Min, Fangying, Jiawei, Meixuan and He (2011: 922) a series of urban environmental problems have occurred in high-density urban environments. The problems include lack of open space, deterioration of the ecological environment, traffic jams, and population overload.

A green rooftop is a planting system that allows for permanent and sustained living plants and covers a significant part of the roof of a building. Green roofs may provide a wide range of economic, environmental and social benefits (Green Roofs, 2006: 1).

Green (vegetated) roofs have been standard construction practice for thousands of years in different countries. It is thus not a new phenomenon (Peck & Kuhn, 2003: 2). Peck and Kuhn (2003: 2) further state that the first known historical references to manmade gardens above ground were the ziggurats stone pyramidal stepped towers of ancient Mesopotamia, built from the fourth millennium until around 600 B.C. In the thirteenth century France planted gardens on top of the Benedictine abbey. Centuries ago, the Norwegians developed sod (plant and soil layers) roofs specifically for thermal insulation purposes. Norway and the United States use sod homes as protection against extremely cold weather. According to Magill, Midden, Groninger and Therrell (2011: 2), Canada has Viking and French examples of sod roofs which are found in Newfoundland and Nova Scotia. During the middle ages and the Renaissance, the rich owned roof gardens as did the Benedictine monks. Between 1933 and 1936, five roof gardens were constructed on top of the seventh floor of the Rockefeller

Centre in New York City. This was designed for enjoyment purposes for the tenants. Tenants pay higher costs for the luxury of having a garden view (Wark, C.G. & Wark, W. W., 2003: Online).

According to Peck and Kuhn (2003: 3), green roofs were considered part of domestic and functional architecture up until the mid-twentieth century. Peck and Kuhn (2003: 3) further state that in the 1960's, concerns started growing regarding the degraded quality of urban spaces and green spaces that are rapidly declining. This is when renewed interest was taken in green roofs in Northern Europe. Breuning (2014: Online) states that modern green roof technology was initiated in the early seventies in Germany. Germany started doing research and studies regarding drainage, root-repelling agents, membranes, plant suitability, and lightweight growing media. Green roof systems were marketed and developed on a large scale. In Germany, green rooftops started expanding rapidly in the 1980's. The annual growth rate for green rooftops is 15-20%. It ballooned from 1 to 10 million square metres of green rooftops by 1996. This growth was stimulated mostly by municipal grants, state legislation, and incentives of between 35-40 Deutsch Mark per square meter of green rooftops. Other countries including the USA, Denmark and Singapore have adopted similar support (Ansel & Appl, 2009: Online). According to Kaluvakolanu (2006: Online) green roof systems are becoming increasingly popular in the USA; however, green rooftop systems are not as common as in Europe, where cities, including Basel in Switzerland, incorporate green rooftops into the building regulations (Kazmierczak & Carter, 2010: 3). Stuttgart's regulations require that all new industrial, flat-roofed buildings must have a green rooftop (Peck & Kuhn, 2003: 3).

According to Peck and Kuhn (2003: 3), Vienna provides funds for new green rooftops at the planning stage, installation thereof and for maintenance three years post installation of green rooftop systems. There may currently be over 75 European municipalities that provide requirements for the installation of green rooftops. Botes (2013: Online) states that green roofs have become more popular in South Africa in the last nine years although it is still a new concept to the majority of the population.

Castello (2011: 321) explains the concept of 'urban brownfields' as vacant space in cities that was previously used, but currently has no function. The 'brownfields' are associated with post-industrial landscapes. Castello (2011: 321) proposes that the vacant land to be used the fullest potential in order to promote a sustainable city. Greening 'brownfields' may bring ecological benefits and in addition cleaning up the environment.

According to McConnachie, Shackleton and McGregor (2008: Online) developing countries lack efficient research regarding urban green space. Fikret oglu Huseynov (2011: 534) acknowledges the importance of green spaces; as such green spaces serve as a place of identity, memory and belonging.

2.3 GREEN ROOFTOP SYSTEMS

According to Carpenter (2014: 4) a green rooftop is a vegetated landscape that is built up from various layers that are installed on top of a roofing system. The green rooftop system may either consist of 'loose laid' sheets or modular containers. According to Peck and Kuhn (2003: 4) a green rooftop system could easily be confused with a traditional roof garden. A traditional roof garden consists mainly of freestanding containers and planters that have been placed on an easy accessible roof, balcony or deck. A contemporary green rooftop system consists of the following:

- The vegetation, selected for a particular application,
- A planting/growing medium, non-soil based planting medium,
- A filter cloth, containing the roots and the growing medium, for water to penetrate it,
- A drainage layer,
- Waterproofing, including a root repellent to protect the membrane from root damage,
- The roof structure, with insulation below or above (Biello, 2014: Online).

2.3.1 Vegetation

The limitations for the vegetation suitable for rooftops are geographical location, climate, structural design, availability of maintenance, and the depth of the planting medium. Plants thriving in shallow planting medium seem ideal for rooftops. According to C.G. Wark and W.W. Wark (2003: Online) a succulent ground cover (sedum) has become popular to use on green rooftops in North America. Hearty wildflowers and grasses with shallow roots are commonly used on rooftops (Wark, C.G. & Wark, W. W., 2003: Online).

According to GreenGrid (2014: Online) the plants that should be considered for an extensive green rooftop system includes deciduous, semi-evergreen, and evergreen 'base' species with 'accent' species. The base mix is composed of five to eight different species of Sedum with one or two accent species. An intensive green rooftop system may include a variety of native groundcovers, perennials, grasses, shrubs and/or even trees.

Greenstone, Burring, Hickman and Nichols (2011: Online) state that the ideal vegetative layer to be applied to a green roof need to have the following characteristics:

- Drought resistant,
- heat tolerant,
- low growing,
- self-seeding,
- wind resistant,
- and survive in extreme growing conditions.

When selecting the plants, it is important to ensure that the plants have been acclimatised to withstand the conditions as mentioned by Greenstone *et al*. (2011: Online).

2.3.2 Planting medium

Planting medium is a mix of minerals, which is synthetically produced, expanded clay. According to Mississippi State University (2014: Online) Planting media is easily confused with soil. The clay is considerably less dense than natural minerals and soil and is therefore lighter. Expanded clay is more absorbent than natural soil. A form of synthetically produced, expanded clay is called perlite, which is found in planting mix (not planting soil) at nurseries. According to C.G Wark and W.W. Wark (2003: Online) there is a large number of planting medium recipes commercially available. The densities of these mixes range from 400kg per cubic metre to 900kg per cubic metre. The planting medium may absorb 20-200% of its weight.

According to Skinner (2014: Online) planting media for green rooftop systems need to have the following characteristics:

- Provide a stable structure for the anchorage of the plants' root systems,
- be as lightweight as possible to prevent excess loading,
- water permeable,
- retain water,
- resist rot,
- provide nutrients,
- possess chemical, physical, and biological characteristics necessary for supporting and sustaining vegetation.

2.3.3 Containment

With a modular system, the substrate, drainage and plants are contained within a lightweight high-density polyethylene module. The dimensions of the modules may vary. These modules are interlocked and form continuous roof coverage. In non-modular systems, the planting medium is applied on top of the entire roof surface. The green roof system is contained by the parapet walls of the roof or by a plastic or metal barrier (Velazquez, 2003: Online).

2.3.4 Drain layer

According to American Wick Drain (2014: Online), drainage is essential for managing the water content in the growing medium. Excess water may cause roots to rot and too little water may result in poor vegetation growth.

Green Roof Solutions (2014: Online) states that the most critical role of the drainage layer is to provide adequate flow of water to a point where it goes off the roof. The flow of water is needed during and after a rain event. The design of a drainage layer allows for some of the stormwater to be retained. The design ensures that stormwater may be used by the plants for a longer time without oversaturation of the vegetation.

Miller (2015: Online) concludes that the drainage system needs to maintain optimum growing conditions for the vegetation and manage heavy rainfall without sustaining damage due to erosion or ponding of water.

2.3.5 Protective layer

According to Conservation Technology (2008: Online) a protective layer, known as the root barrier, is needed if the waterproofing membrane is not resistant to root penetration. The membrane of the roof needs protection, firstly, against damage when installing the green rooftop system, and against root penetration and fertilizers (Miller, 2015: Online). Not all green roof systems require a protective layer. The protective layer may be a sheet of rigid insulation, slab of lightweight concrete, copper foil, thick plastic sheet, or even a combination of the above. The selection depends on the design of the green rooftop system (Wark, C.G. & Wark, W. W., 2003: Online).

2.3.6 Insulation

According to Greenroofs (2014: Online), insulation is an optional layer in a green roof system. Insulation helps regulate the temperature of the building. The design of the green roof system will influence the placement of the insulation, which may be placed under or over the roof deck, or over the waterproofing membrane.

2.3.7 Waterproofing

According to the SANS 10400 Building Regulations (2008: 85), roofs must be able to resist penetration of water to the extent that water penetrating the roof will not run down the inside face of the walls onto the floor, or damp patches on the ceiling or floor.

2.3.8 Irrigation

There are different kinds of irrigation methods that may be used on rooftops. The passive irrigation method is when rainwater is being stored in the drain layer. The rainwater eventually wicks back up through the planting medium and excess water drains off. Polypropylene fiber mat is a type of water storage medium that may be put directly below the planting medium and acts as a sponge. Another type of irrigation system includes small reservoirs in the drain mat. Expanded clay fills the drain mat up to the bottom of the planting medium. When sedums and drought-tolerant plants are used, irrigation is rarely necessary (Wark, C.G. & Wark, W. W., 2003: Online). According to Carpenter (2013: 26), rainfall is generally not efficient to support a green rooftop throughout the year. It is important to establish whether the rainwater or another source may be harvested from another area on the site, and stored to supply the irrigation system of the green rooftop. This may minimize or eliminate the use of potable water for irrigation.

Distinctive Design Group (2014: Online) offers two main types of irrigation systems in Gauteng. The sprinkler system and drip irrigation system. The sprinkler system may be set on a timer, which saves water and effort. The drip irrigation system allows water to drip to the root of a plant using a network of pipes, drippers, valves and tubes. Pressurised water or an electric pump is used to send water to the base of a plant using narrow tubes. According to Distinctive Design Group (2014: Online) water and fertilizer are saved by using the drip irrigation system.

Some of these elements may be combined and need not be individual units. For example, a filter layer may be used as a water storage mat. The combination of elements could reduce the cost and weight of the rooftop system (Wark, C.G. & Wark, W. W., 2003: Online).

2.4 TYPES OF ROOFTOP SYSTEMS

There are three basic types of green rooftop systems:

- Extensive
- Semi-intensive
- Intensive (National Roofing Contractors Association (NRCA), 2007: 27).

The three types of green rooftop systems are mainly differentiated by the depth of the growing medium (Peck & Kuhn, 2003: 4).

2.4.1 Extensive green rooftops

Extensive green rooftops are known as low-profile or low performance green systems. It is designed for hydrological and thermal performance while it has minimum weight. It may or may not be aesthetically pleasing (Carpenter, 2013: 4).

Extensive green rooftops are typically not easily accessible and are characterized by the following:

- It is shallow and lightweight, which means that the supporting structure required, may be less strong than the supporting structure for semi-intensive or intensive green rooftop systems,
- it has a low capital cost,
- the plant diversity is low, and
- maintenance required is minimal (Grové, 2012: Online);
- the roof frame may consist of either concrete, wood or steel; and
- the plant mix may consist of sedums, moss and perennials (Vegetal Innovation & Development (VID), 2013: 12).

The planting medium consists of a mixture of gravel, crushed brick, sand, peat, Light Expanded Clay Aggregate (LECA), organic matter, and soil. The depth of the planting medium varies from 5cm to 15cm. The weight of the planting medium between 72.6-169.4kg/m^2 when fully saturated. Some rooftops have an extreme desert-like microclimate. This together with the shallow planting medium allows for low hardy plants like succulents to survive. The plants that seem to survive the shallow planting medium and desert-like microclimate are dryland, alpine and indigenous plants. These plants need to be fertilized and watered only until they are established. After that, maintenance consists of yearly checkups for invasive species, membrane inspection and safety (Peck & Kuhn, 2003: 4).

Extensive green rooftops use a narrow range of species and are limited to low-growing grasses, mosses, herbs, and draught-tolerant succulents like sedum. The latter is a plant variety that can tolerate extreme conditions. These types of plants are comfortable growing in the shallow planting medium as well as steeper slopes. The slopes can be steeper than 9 degrees (NRCA, 2007: 30).

Figure 2.1 illustrates a section through an extensive rooftop system.

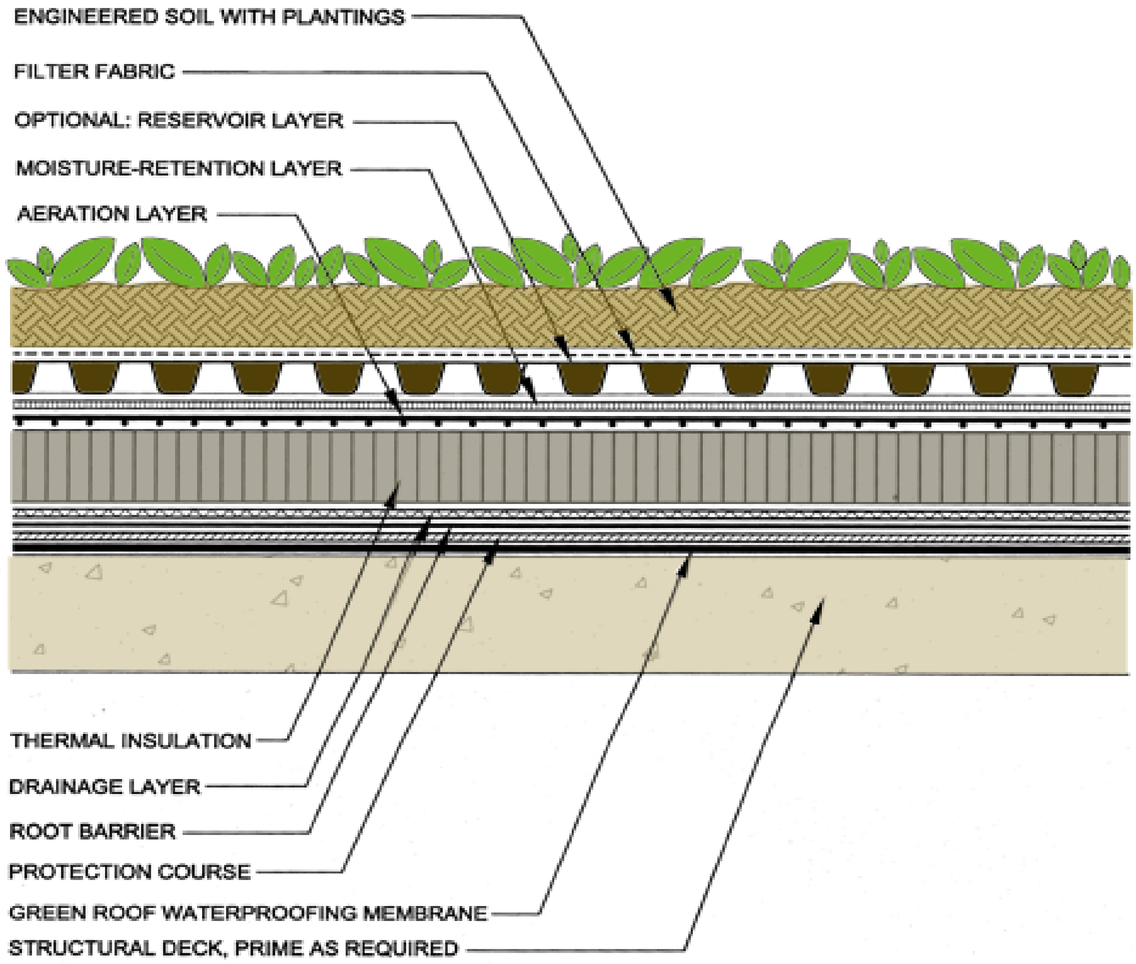

Figure 2.1: A section through an extensive rooftop system.

(NRCA, 2007: 30)

Figure 2.1 illustrates eleven potential layers of an extensive green rooftop system. The eleven layers consists of engineered soil 5-15cm deep with low plantings, filter fabric, reservoir layer (optional), moisture-retention layer, aeration layer, thermal insulation, drainage layer, root barrier, protection course, green roof waterproofing membrane and structural deck, prime as required. Figure 2.1 defines the extensive green rooftop system thoroughly and may be used as a guideline in South Africa for constructing extensive green rooftop systems.

Figure 2.2 is a photo of an extensive rooftop system.

Figure 2.2: An example of an extensive rooftop system.

(Peck & Kuhn, 2003: 2)

Figure 2.2 illustrates an example of an extensive green rooftop built on a roof with a slope. Access is not needed to the roof. The plants survive by themselves. In South Africa, this method may be applied as well in order to do as little damage as possible to the vegetation and to contribute to sustaining the natural environment.

2.4.2 Semi-intensive green rooftops

Semi-intensive rooftops may be either easily accessible or not easily accessible. A semi-intensive green rooftop system may accommodate more plant species than the extensive green rooftops. Plants like small shrubs, grasses and herbs may form part of the semi-intensive green rooftop. The slope of the roof structure is, however, limited to a lower slope. The slopes may be 9 degrees or less. The depth of the planting medium may vary from 15-25cm. The saturated weights for this system may vary from 169.4-290kg/m^2. The landscaping for the semi-intensive green rooftop system requires less regular maintenance than the extensive rooftop system.

The plant diversity is, however, still quite limited due to the shallow planting medium. The semi-intensive green rooftop system may require irrigation and a reservoir layer (NRCA, 2007: 31).

Figure 2.3 illustrates a section through a semi-intensive rooftop system.

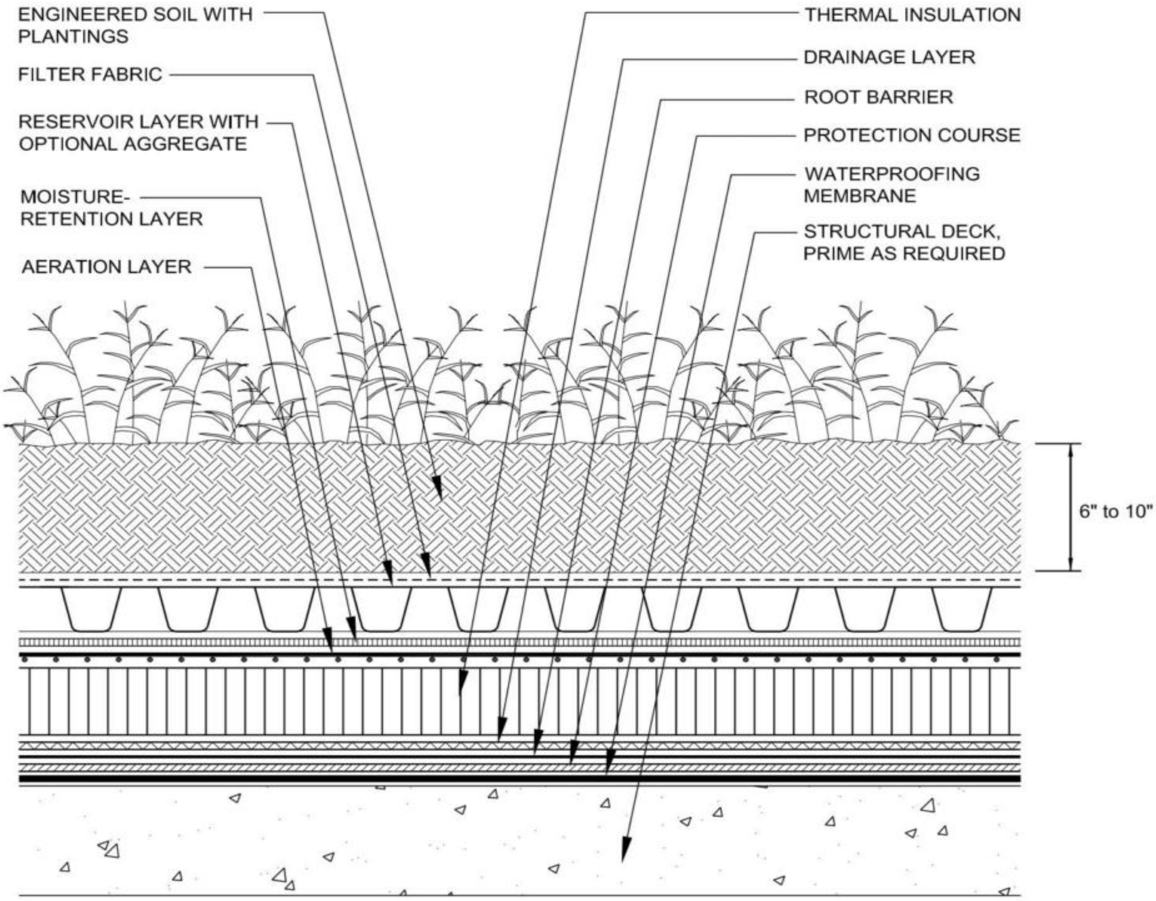

Figure 2.3: A section through a semi-intensive rooftop system.

(NRCA, 2007: 31)

Figure 2.3 illustrates eleven potential layers of an extensive green rooftop system. The eleven layers consists of engineered soil 15-25cm deep with medium height plantings, filter fabric, reservoir layer (optional), moisture-retention layer, aeration layer, thermal insulation, drainage layer, root barrier, protection course, green roof waterproofing membrane and structural deck, prime as required. Figure 2.3 defines the semi-intensive green rooftop system thoroughly and may be used as a guideline in South Africa for constructing semi-intensive green rooftop systems.

Figure 2.4 is a photo of a semi-intensive rooftop system.

Figure 2.4: An example of a semi-intensive rooftop system.

(Zinco, 2001: Online)

Figure 2.4 shows that a semi-intensive green rooftop system may have a variety of different types of shrubs and it may be designed to be aesthetically pleasing. The semi-intensive green rooftop system, as shown in figure 2.4, does not need a large area to be attractive and practical. Figure 2.4 is an excellent example of the potential of a semi-intensive green rooftop system and South African developers may use it as inspiration and guideline for future developments.

2.4.3 Intensive green rooftops

Intensive green rooftop systems are known as a high-profile green rooftop system, or generally as a rooftop garden (Wark, C.G. & Wark, W. W., 2003: Online). Intensive green rooftops are typically easily accessible and are characterized by the following as compared to the previous two categories:

- It has deeper soil and thus weighs more per square metre,
- it has higher capital costs,
- the plant diversity is higher,
- it requires more maintenance (Grové, 2012: Online).

The growing medium usually consists of soil based mixtures. The depth of intensive green rooftops may vary from 20-60cm deep.

The saturated weight seems to be between 290-967.7kg/m². Trees and shrubs may be included in the green rooftop because of the increased soil depth. This means that the plant selection may be more diverse and may include shrubs and trees. This allows for a more complex ecosystem. Maintenance, however, is more demanding. The plants need to be watered regularly. A specialized irrigation system is often specified. A structural engineer may need to be consulted as well as a horticultural specialist. It is recommended that the installer is experienced (Peck & Kuhn, 2003: 5).

The wide variety of plants that are accommodated by the intensive green rooftop system may include shrubs and trees. The slope of the intensive green rooftop system is limited to 1.2 degrees or less. The Intensive green rooftop systems typically require an irrigation system and a heavy root barrier. A reservoir layer will be needed for these systems. Due to the quantity of water that comes from the irrigation and weather conditions, an efficient drainage layer is required (NRSC, 2007: 32).

Figure 2.5 illustrates a section through an intensive green rooftop system.

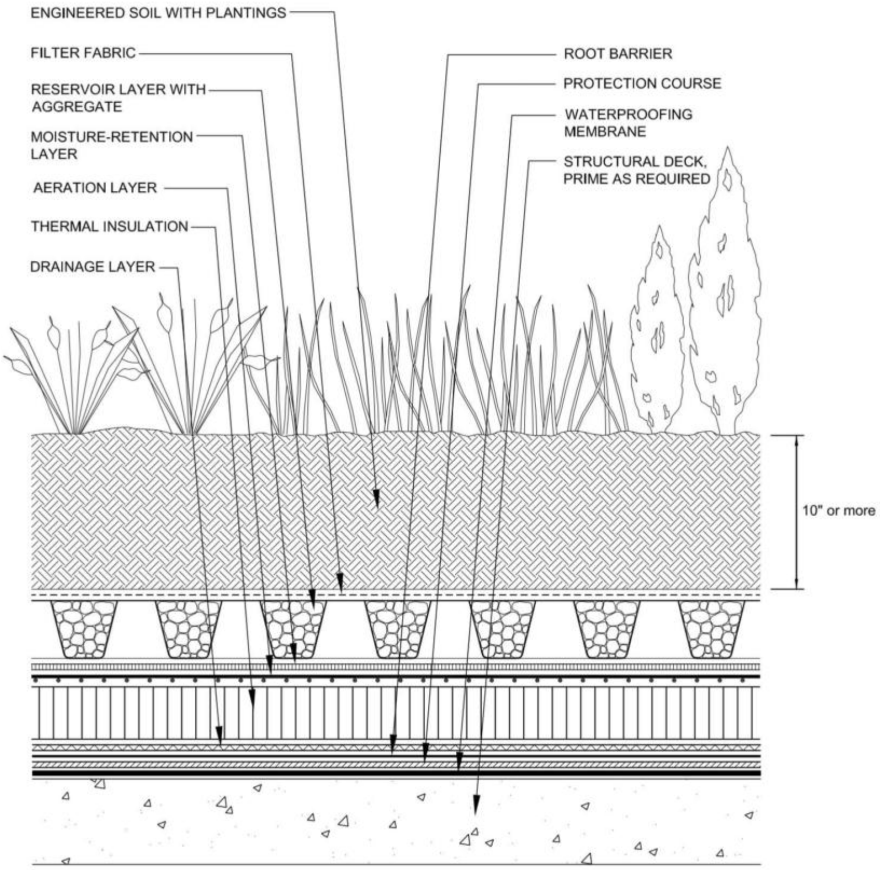

Figure 2.5: A section through an intensive green rooftop system.

(NRSC, 2007: 32).

Figure 2.5 illustrates eleven potential layers of an extensive green rooftop system. The eleven layers consists of engineered soil 20-60cm deep with medium high plantings that may include trees, filter fabric, reservoir layer (optional), moisture-retention layer, aeration layer, thermal insulation, drainage layer, root barrier, protection course, green roof waterproofing membrane and structural deck, prime as required. Figure 2.5 defines the intensive green rooftop system thoroughly and may be used as a guideline in South Africa for constructing intensive green rooftop systems.

Figure 2.6 is a photo of an intensive rooftop system.

Figure 2.6: An example of an intensive green rooftop system.

(NRSC, 2007: 32)

Figure 2.6 illustrates that an intensive green rooftop system may have a wide variety of plants, which may include trees. The rooftop is easy accessible. It may be a recreational area where people may relax and enjoy the fresh air. Figure 2.6 is an example of the potential of an extensive green rooftop system in a densely built urban area. Cities in South Africa, for example Johannesburg, may use this example to see what the potential of such a green rooftop system may be and to improve on the green areas in the cities.

Factors like location, budget, structural integrity, client needs, and the availability of material and plants contribute to the specific green rooftop. Each rooftop will thus be different. The green rooftop system may even be a combination of the intensive and extensive rooftop system (Peck & Kuhn, 2003: 5).

2.4.4 Modular rooftop system

In some cases, the entire green rooftop system is contained in special gardening trays that cover most of the roof or the entire roof. In a non-modular system, the planting medium is a continuous layer over the entire roof and is contained by the border of the roof, which may be a parapet wall (Wark, C.G. & Wark, W. W., 2003: Online).

According to Van Niekerk *et al.* (2011: 24), a modular green rooftop system has the following characteristics set out in Table 2.1.

Table 2.1: Modular characteristics

	MODULAR CHARACTERISTICS
Weight	Modules may be installed on any existing roof surface that is in a good condition and with sufficient weight load capacity. Modules may even be installed on corrugated roofs with a pitch up to 15 degrees.
Installation	Installing a modular green rooftop system may be quick, because the modules may be pre-planted off site. The installation of a modular system may be done by an amateur as it is a user-friendly technique.
Costs	A modular system may be slightly more expensive than an extensive green rooftop system due to the cost of the modules.
Repair and maintenance	The modules may be moved easily without disturbing the plants and growing medium.
Alterations and additions	Modules may be added and installed in sections. Future add-ons and alterations are thus always an option.
Plants	The modules may constrain root growth, which may cause some plants to struggle.

(Van Niekerk *et al.*, 2011: 24)

Table 2.1 summarizes the characteristics of a modular system. Modules may be installed on any existing roof surface that is in a good condition and with sufficient weight load capacity. Modules may even be installed on corrugated roofs with a pitch up to 15 degrees. Installing a modular green rooftop system may be quick, because the modules may be pre-planted off site.

The installation of a modular system can be done by an amateur as it is a user-friendly technique. A modular system may be more expensive than an extensive green rooftop system due to the cost of the modules. The modules seem to allow movement without disturbing the plants and growing medium. Modules may be added and installed in sections. Future add-ons and alterations are an option. The modules may constrain root growth, which may cause some plants to struggle. The modular system seems to be easier to install on existing roofs than other green rooftop systems. South Africans may apply the characteristics, advantages and disadvantages of the modular system to determine whether the system may work on a rooftop.

Table 2.2 gives the comparison of the extensive, semi-intensive and intensive green rooftop systems

Table 2.2: Comparison of the main types of green rooftop systems

CRITERIA	**EXTENSIVE GREEN ROOFTOP**	**SEMI-INTENSIVE GREEN ROOFTOP**	**INTENSIVE GREEN ROOFTOP**
Vegetation	Sedums, moss, perennials	Perennials, small shrubs, lawn	Shrubs, trees, lawn
Plant diversity	Low plant diversity	Medium plant diversity	High plant diversity
Planting Medium	5-15cm deep	15-25cm deep	20-60cm deep
Weight	72.6-169.4kg/m²	169.4-290kg/m²	290-967.7kg/m²
Irrigation	No	Yes	Yes
Structural Frame	Wood, steel, concrete	Concrete	Concrete
Roof pitch	Up to 30 degrees	Up to 9 degrees	1.2 degrees or less
Maintenance			
Roof Cost	R	RRR	RRRR
Accessibility	Often inaccessible	Limited	Highly accessible

(Peck & Kuhn, 2003: 5; VID, 2013: 12)

Table 2.2 is a comprehensive comparison of three types of green rooftop systems, namely the extensive green rooftop system, semi-intensive green rooftop system, and the intensive green rooftop system. Different criteria are compared.

The criteria includes vegetation, the plant diversity, the depth of the planting medium, the weight per square meter, the need for irrigation, the structural frame needed, the roof pitch, the maintenance required, the average cost, and the accessibility required.

The extensive green rooftop system has sedums, moss, and perennials as part of the vegetation. The plant diversity is low. The planting medium is on average 5-15cm deep. The extensive green rooftop system weighs on average between 72.6 and 169.4kg per square metre. No irrigation is required. The structural frame may be of wood, steel or concrete. The roof pitch may be up to 30 degrees. The extensive green rooftop system requires the least maintenance and it costs the least. Accessibility is not a requirement.

The semi-intensive green rooftop system has perennials, small shrubs, and lawn as part of the vegetation, which means that it has a medium plant diversity. The planting medium is on average 15-25cm deep with an average weight of between 169.4 – 290kg per square metre. Irrigation is required. The structural frame need to be of concrete and the roof pitch may not exceed 9 degrees. The semi-intensive system requires more maintenance than the extensive system. The cost of the semi-intensive system is between the costs of the extensive and intensive system. Access is only needed for the maintenance crew. If the space will be used as a recreational space, then access is required for the public.

The intensive green rooftop system has lawn, trees and shrubs as part of the vegetation. It has thus the highest plant diversity and the planting medium is the deepest, 20-60cm deep. The intensive rooftop system is the heaviest, 290-967.7kg per square meter. Irrigation is required. A concrete roof structure is required. The roof pitch may not exceed 1.2 degrees. Compared to the other two rooftop systems the intensive system requires the most maintenance and it costs the most. The main reason for an intensive rooftop system is for recreational purposes and accessibility is thus a priority.

2.5 CONCLUSION

Green rooftop systems are not a new phenomenon. It has been in use for thousands of years for domestic and functional purposes. In the 1960’s, concerns started growing regarding the degraded quality and lack of green vegetated spaces in urban areas. Northern Europe started doing research and developing commercial green rooftop systems.

A green rooftop system consists of different layers. These layers include the following: vegetation, planting/growing medium, filter layer, drain layer, protective layer, waterproofing, insulation, irrigation and roof structure.

There are three main types of rooftop systems: Extensive, semi-intensive and intensive systems. These systems are differentiated by the depth of the planting medium and the amount of maintenance needed.

Extensive green rooftop systems have a shallow planting medium; it is the lightest and cheapest green rooftop system and requires minimal maintenance. The system is lightweight and thus might not require additional reinforcement. The extensive system is suitable for large areas. Irrigation is often not required. Less technical expertise is required. The extensive rooftop systems may be suitable for retrofit projects. Authorities may include the extensive system as a requirement for building approval. The extensive system presents naturally and the vegetation may be left to grow spontaneously. The extensive green rooftop system is less energy efficient than the other systems. The vegetation is limited, access is limited and to some, the garden may be visually unattractive.

A semi-intensive green rooftop system has a slightly deeper substrate, is more expensive and requires more maintenance than the extensive green rooftop system.

Intensive green rooftop systems are known as roof gardens. It has a deep planting medium which may accommodate a wide variety of plants. An intensive green rooftop system is an expensive green rooftop system and requires intensive maintenance. The intensive green rooftop system has more energy efficiency and stormwater retention capabilities compared to the other systems. The insulation properties of the intensive green rooftop system are better than those of the extensive and semi-intensive green rooftop systems. The intensive system may simulate a wildlife garden. The diversity of vegetation and habitats are greater. The intensive system is usually attractive visually. The system requires irrigation which might prove to be a problem in countries with periodic drought, such as South Africa. The intensive green rooftop system has the greatest weight loading on the roof. The system has the highest maintenance and capital cost compared to the extensive and semi-intensive systems. This system might be more complex and thus requires more expertise.

This comprehensive comparison might contribute to the decision making of what green rooftop system to install. Each development is unique and each developer has a criteria. By knowing the advantages, disadvantages, and criteria of each green rooftop system, it might contribute to making the right choice.

The advantages, disadvantages and effects that green rooftops in a city might bring are important to consider, as this effects all the citizens of the involved city. The potential effects will be discussed in the next chapter.

CHAPTER 3: THE EFFECT OF GREEN ROOFTOPS IN CITIES

3.1 INTRODUCTION

It is important to investigate the potential effects of green rooftop systems. This may influence the validity of green rooftop systems in South Africa.

According to Song (2011: 144), cities are unable to meet the functional needs of the expanding population due to the rural population that migrates to the urban cities. The daily discharge of wastewater, waste gas, waste, and noise are far more than the self-purification capacity of the natural environment can bear.

Song (2011: 144) states that as the population increases, the demand for food increase in such a way that the available agricultural land cannot sustain the population.

3.2 ENERGY SAVINGS

The green rooftop system acts as insulation. In summer, the green plantings on the roof shades the building from solar radiation. Through the process of evapotranspiration, the green rooftop system may reduce or eliminate heat gain. Evapotranspiration thus helps to cool the surrounding area. Due to the cooler surroundings, the building requires less energy to cool the building (Biello, 2014: Online). According to Carpenter (2014: 9) the green rooftop system reduces the heat transfer through the roof and ambient temperature on the roof surface.

In winter, the growing medium provides an additional layer of insulation. This decreases the amount of energy needed to heat the building. The extent of the energy cost savings may differ from building to building. Impacting factors of the amount of energy savings include the size of the building, the building's location, the depth of the growing medium and the type of plants (Peck & Kuhn, 2003: 6).

According to Peck and Kuhn (2003: 6) when the outside temperature is -20º C, 30cm of the growing medium will not experience temperature drops below 0º C. However, the reduced need for air conditioning in summer is greater than the value added to the insulation in winter.

According to Carpenter (2014: 8) research results vary in how much difference in temperature and amount of energy savings there are between buildings with green rooftop systems and building with conventional roofs. The variety in the research results is because the amount of energy saved is dependent on the following:

- The percentage of the entire roof of the building that is covered by a green rooftop system.
- The thickness of the insulation.
- The height of the building.
- The number of storeys in the building. The floor directly below the green rooftop receives the most benefit.
- The roof to wall ration.
- The general climate of the area and the microclimate of the building.
- The efficiency of the HVAC system.

Due to the variety of variables, when the roof is being designed, all the factors that contribute to energy saving need to be taken into account in order to maximize the energy saving. According to Carpenter (2014: 9) the best results may be achieved in buildings with fewer than four storeys, a higher percentage of green roof coverage, deeper planting medium, and vegetation with large leaves.

According to the European Federation of Green Roof Associations (EFB) (1999: Online) a green roof does not only act as insulation. The combination of the plant processes, which include photosynthesis and evapotranspiration as well as the soil processes, evapo-transmission reduces the amount of solar energy that is being absorbed. The temperature beneath the roof is thus cooler due to the insulation properties, plant processes, and soil processes of a green rooftop system.

Research done by Nottingham Trent University cited in EFB (1999: Online) has concluded the following:

In summer, when the mean temperature is 18.4 ºC, the temperature beneath the membrane of the conventional roof is 32ºC and the temperature beneath a green rooftop system is 17 ºC. In winter, when the mean temperature is 0 ºC, the temperature beneath the conventional roof is 0.2 ºC and the temperature beneath the green rooftop system is 4.7 ºC (EFB, 1999: Online). Research indicates that green rooftop systems have insulation and thermal properties. It contributes to energy savings in summer as well as in winter. The energy savings is, however, more in summer than in winter.

Liu (2002: Online) compiled the following graph shown in figure 3.1 that indicates the fluctuation of daily temperatures of a conventional roof, ambient temperature, and a green roof.

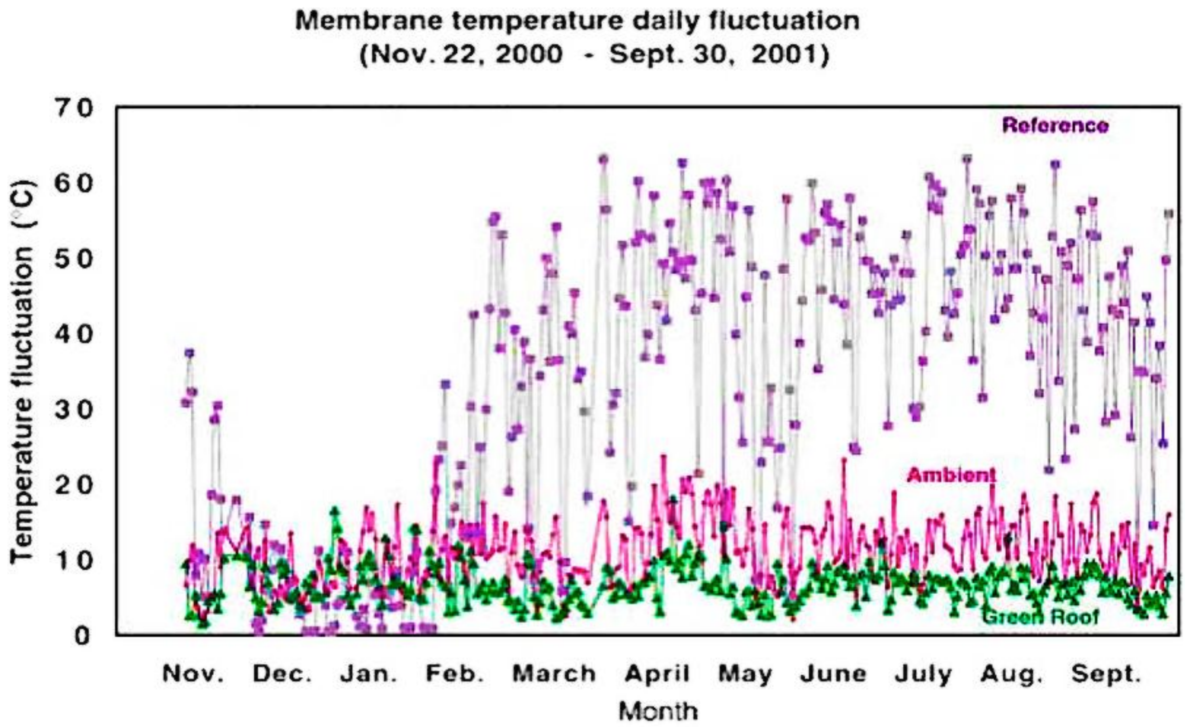

Figure 3.1: Fluctuation of daily temperatures of a conventional roof, ambient temperature, and a green roof.

(Liu, 2002: Online)

In figure 3.1, the daily temperature fluctuations are shown for a conventional roof, the ambient temperature, and the temperature of a green roof. The temperature of the green roof is lower than the ambient temperature in the months February, March, April, May, June, July, August, September and November. In December and January, the temperature of the green roof is slightly warmer than the ambient temperature. The temperature of the conventional roof is drastically higher than the ambient temperature in summer and cooler than the ambient temperature in winter.

This shows that green rooftop systems contributes to energy saving due to less air conditioning needed in summer and less heating needed in winter compared to conventional roofs.

3.3 LIFE EXTENSION OF THE ROOF MEMBRANE

According to Grové (2012: Online) and Miller (2015: Online) the green rooftop system protects the roofing membrane from extreme temperature fluctuations. The green rooftop system protects the roofing membrane from the negative impact of ultraviolet radiation and damage due to pedestrian traffic.

According to Greenroofs (2013: Online) green rooftop systems may increase the lifespan of a conventional roof by double the time, which prolongs the practical life of the roof to 20 years. Therefore, the replacement of the roof or rehabilitation may be delayed. This contributes to the cost effectiveness of green rooftop systems.

3.4 SOUND INSULATION

Green rooftop systems may be designed to insulate sound (Grové, 2012: Online). The growing medium may block the lower frequencies of sound and the plants may block the higher frequencies of sound. According to Peck and Kuhn (2003: 7) tests show that 12cm of growing medium may reduce sound by up to 40 decibels.

Van Renterghem and Botteldooren (2008: Online) conducted an experiment to determine the sound attenuation by a green roof measured in decibels. Figure 3.2 illustrates the results of the sound attenuation of different substrate thickness and different sound frequencies.

Figure 3.2 graphs the sound attenuation by a green roof, comparing different frequencies and different substrate thicknesses.

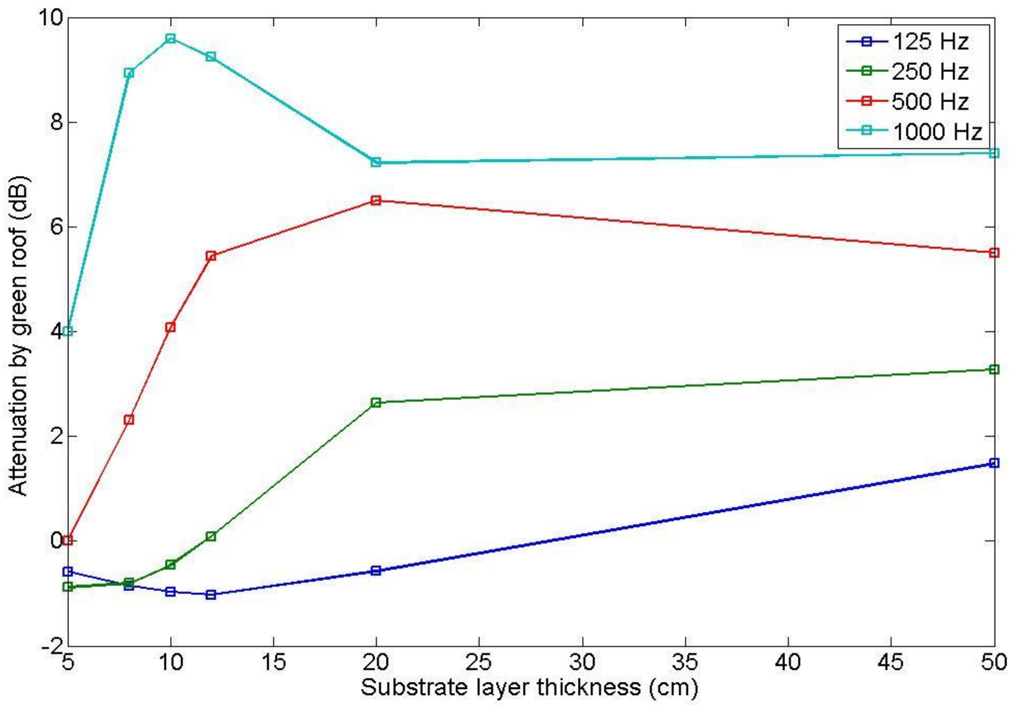

Figure 3.2: Sound attenuation by green roof comparing different frequencies and different substrate thicknesses.

(Van Renterghem & Botteldooren, 2008: Online)

In Figure 3.2, the sound attenuation of 10 different substrate thicknesses were tested and four different frequencies were compared. The substrate thicknesses included 5mm up to 50mm in 5mm stages. The frequencies used were 125Hz, 250Hz, 500Hz and 1000Hz. The higher the frequency, the better the sound attenuation. This is due to the fact that low frequencies have large wavelengths that are not capable of entering the growing medium, and thus no or little attenuation occurs. The noise spectrum of traffic is at 1000Hz, and thus green rooftop systems contribute to shielding out some of the noise caused by traffic. The figure illustrates that there is little difference between the sound attenuation of a 20mm thick substrate and a 50mm thick substrate.

Connelly and Hodgson (2008: 4) explain that the larger the percentage of the roof is covered with a green rooftop system, the more sound attenuation will take place. A tilted roof will improve the shielding against noise more than that of a flat roof, because there are more interaction with the sound waves and the substrate.

3.5 FIRE RESISTANCE

According to Peck and Kuhn (2003: 7) green rooftop systems may help to slow down the spread of fire to and from the building through the roof, especially where the growing medium is saturated. However, if the plants are dry, it may present a fire hazard. There should be 'fire breaks' at regular intervals across the entire green rooftop system, along the perimeter and around all the penetrations. The 'fire breaks' need to consist of non-combustible material; for example, concrete pavers or gravel. The 'fire breaks' need to be at least 60cm wide and located every 40m in all the directions. Another option to consider is fire resistant plants such as sedums, because of their high water content. Sprinkler irrigation may be connected to the fire alarm. Single Ply Roofing Industry (SPRI) and Green Roofs for Healthy Cities (2010) developed an external fire design standard for vegetative roofs that has been approved by the American National Standard (ANSI). SPRI and Green Roofs for Healthy Cities (2010: 7) state that vegetative green roofs have an excellent history of resisting fire damage. Succulents, due to their water retention, is highly fire resistant.

3.6 STORM WATER MANAGEMENT

Green rooftop systems absorb, retain and detain stormwater. Green rooftops represent a strategy that contributes to the control of the runoff rainwater in urban environments (Grové, 2012: Online) and (Miller, 2015: Online). Green rooftop systems intercept and retain rainwater from the early part of the storm. Green rooftop systems limit the amount of run-off in larger rainstorms. Water is stored in the planting medium; it is used by or stored in plants' foliage, roots or stems, or it evaporates from the surface. A green rooftop system with a water retention layer may have additional water storage capacity (Carpenter, 2014: 8).

The extent of the stormwater control by the green rooftop system is dependent on the following factors (Carpenter, 2014: 8):

- The depth of the planting medium.
- The depth of the drainage layer.
- The consistency of the planting medium.
- The porosity of the planting medium.
- The structure of the drainage system.
- The slope of the site.
- Plant species.
- The type of drainage system.
- The weather conditions of the region: the length, intensity, and frequency of rain events influence a green rooftop system's ability to retain water.

3.7 URBAN HEAT ISLAND EFFECT

Gardens on roofs could offset the local urban heat island effect and global warming (Biello, 2014: Online).

The Urban Heat Island Effect is the rise in the ambient temperature of an urban area due to hard surfaces in the urban environment such as roads, parking lots, conventional roofs, and buildings (Carpenter, 2014: 9).

Middel, Chhetri and Quay (2015: 178) summarize the impact of the heat island effect as follows: increases air and surface temperature in the urban area; increases of outdoor water use; increase the demand of energy for cooling; lowers air quality; decreases thermal comfort; and increases morality related to heat stress as well as illnesses.

Figure 3.3 illustrates the heat island effect.

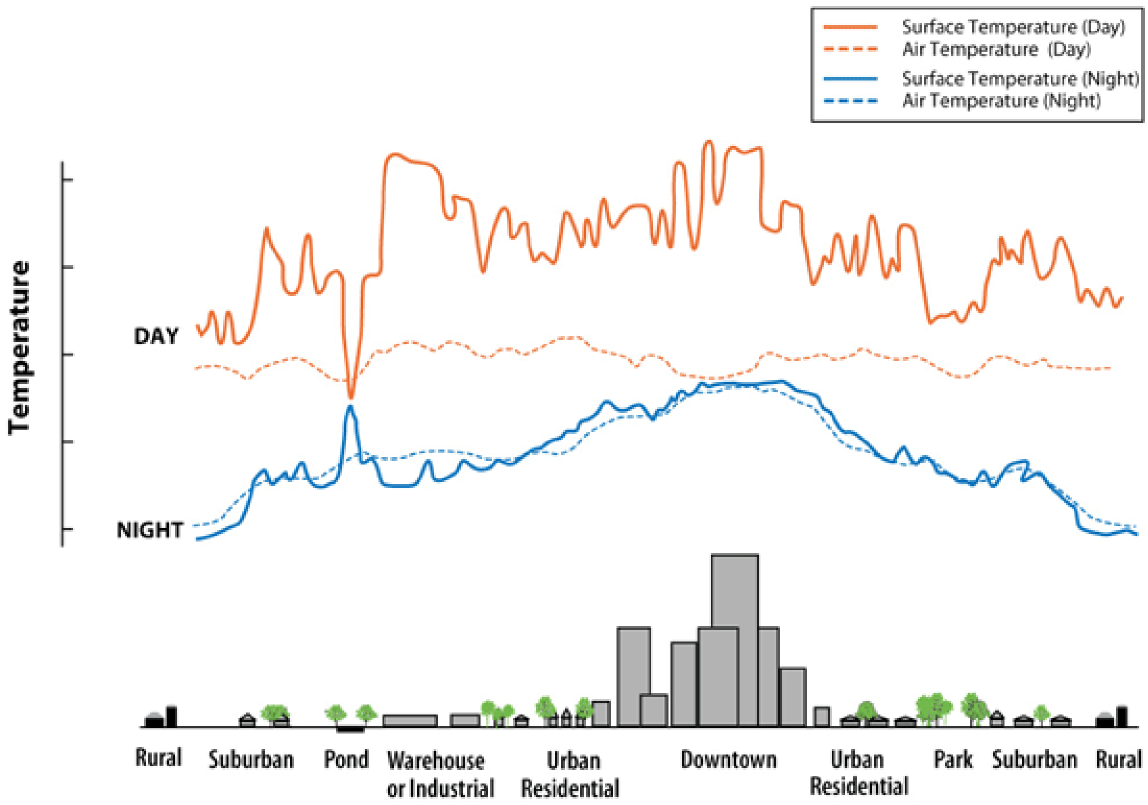

Figure 3.3: The heat island effect

(North Carolina State University, 2013b: Online)

Figure 3.3 illustrates the four different temperatures in an urban area. The four temperatures include the surface temperature during the day, the air temperature during the day, the surface temperature at night and the air temperature at night.

These four different temperatures are compared for seven different areas within the urban area that includes rural, suburban, pond, warehouse/industrial, urban residential, downtown, and a park. The surface temperature during the day is significantly higher than the air temperature during the day in the industrial area and downtown are due to the low albedo of the surfaces in these areas. The more area covered by vegetation, the less the difference in the surface and air temperatures during the day. The surface and air temperature at night are more or less the same. However, both the air and surface temperatures are higher in the downtown and urban residential areas at night.

According to the United States Environmental Protection Agency (U.S. EPA, 2014: Online), during a summer day, roofs and pavement surface temperature may be 27-50º C hotter than the temperature of the air. Shaded and moist surfaces seem to have a temperature similar to the temperature of the air.

These surface temperatures contribute to the atmospheric urban heat islands. According to Rosenburg (2014: Online) the air in an urban heat island may be as high as 11º C higher than rural areas that surround the city.

The urban heat island effect may impact the environment in several ways:

- The increased heat of cities increase the discomfort of the residents.
- More energy is used to cool the temperature down.
- It increases pollution (Rosenburg, 2014: Online)
- Impaired water quality (U.S. EPA, 2013: Online)

According to U.S. EPA (2013: Online), the increased temperatures and higher pollution levels associated with the heat island effect may effect human health and it may contribute to discomfort, respiratory difficulties, heat cramps, exhaustion, heat related mortality, and non-fatal heat stroke.

U.S. EPA (2013: Online) states that the elevated summertime temperatures in cities increase energy consumption for cooling. Electricity demand for cooling increases 1.5-2% for every 0.6º C increase in air temperature.

The heat island effect increases smog (ground-level ozone) production due to the higher urban air temperatures. Smog is created in the air by photochemical reactions of pollutants. These photochemical reactions may be intensified at higher temperatures. As an example, in Los Angeles, smog increases by 5% for every 1º C that rise above 22º C (Akbari, 2005: 2).

U.S. EPA (2013: Online) found that the heated roofs and pavements may heat stormwater runoff. Surfaces with a temperature of 38º C may elevate initial rainwater temperature from roughly 21º C to 35 º C. This heated stormwater may drain into storm sewers and raise water temperature as it runs into streams, rivers, ponds, and lakes. Aquatic life is directly affected by the temperature of the water. Rapid temperature changes in aquatic ecosystems may be stressful or even fatal to aquatic life.

According to Akbari (2005: 3) and Grové (2012: Online) there are two ways to mitigate the heat island effect. A way is to use surfaces with high albedo characteristics. The second option is to increase trees and vegetation in the cities. Cities are already over developed and there is little space for planting vegetation. Rooftops may be transformed into green rooftop systems.

Albedo is the measure of "how much light that hits a surface is reflected without being absorbed" (North Carolina State University, 2013a: Online). Light colours reflect the most light and thus have a high albedo. The darker the color, the more light is being absorbed and the lower the albedo. Albedo is another name for reflectivity.

The albedo of the surface determines how much sunlight will be absorbed. More absorption of sunlight relates to a warmer surface temperature. A surface that reflects most of the sunlight does not change temperature (North Carolina State University, 2013a: Online).

Figure 3.4 illustrates albedo.

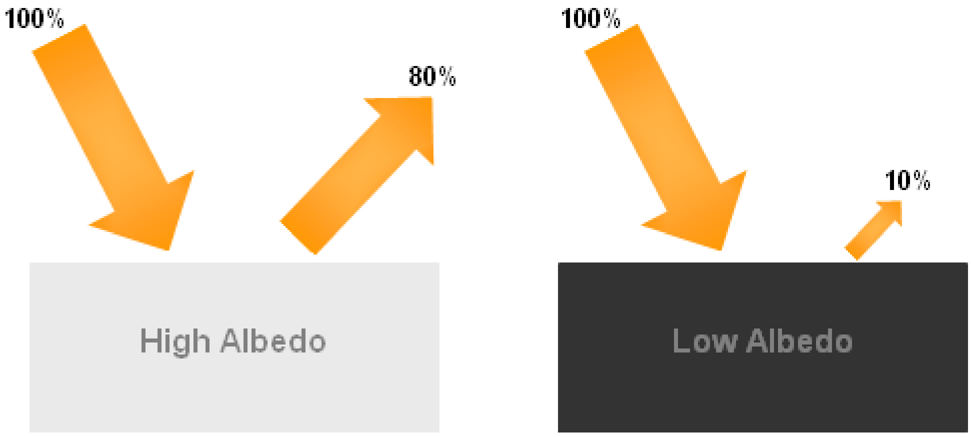

Figure 3.4: High and Low Albedo

(North Carolina State University, 2013a: Online)

Figure 3.4 illustrates that light colored surfaces absorbs only 20% of the sunlight that hits the surface and it reflects 80% of the sunlight. Dark surfaces absorb 90% of the sunlight that hits the surface and reflects 10%.

According to North Carolina State University (2013a: Online) plants have a low albedo. Vegetated areas might reflect 3-20% of the sunlight and absorb the rest. However, plants do not contribute to overall warmer temperatures. The excess warmth is offset by evaporative cooling from transpiration.

Green rooftop systems may mitigate the heat island effect. According to Carpenter (2014: 9), a study in Canada modeled the effect of green rooftop systems on the urban heat island. In the Canada study the conclusion was made that green rooftop systems may reduce local ambient temperature by 0.5º C - 2º C.

Figure 3.5 illustrates the direct and indirect benefits of cool surfaces.

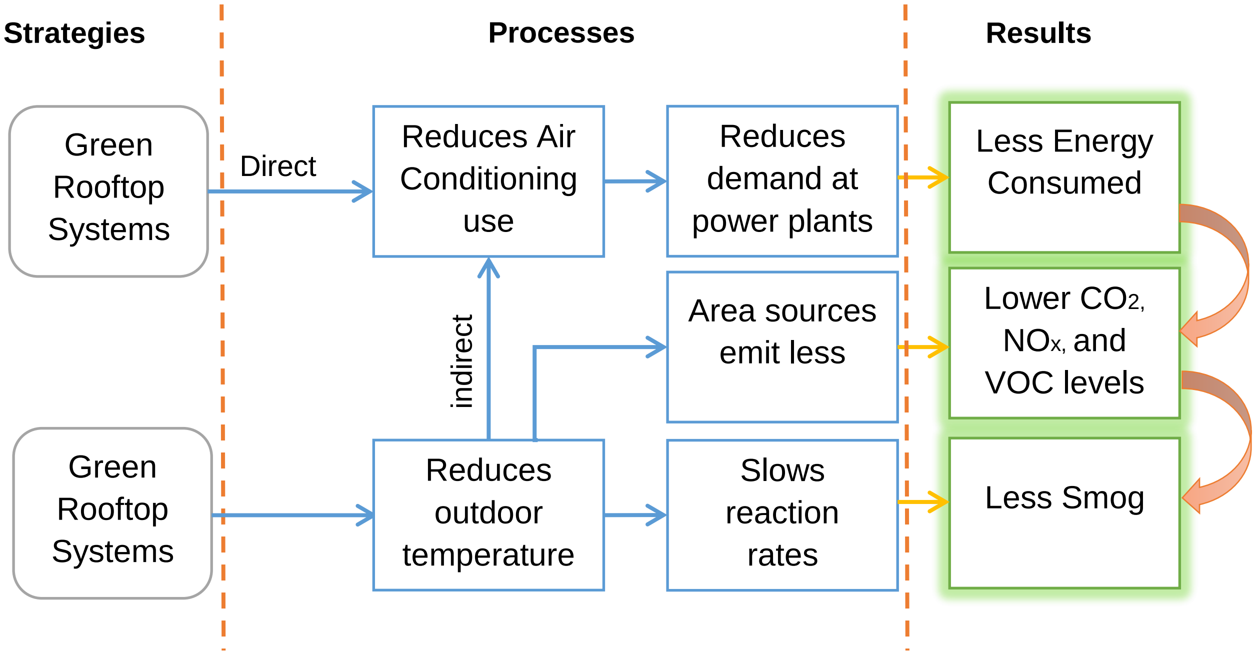

Figure 3.5: Green rooftop systems mitigating the heat island effect

(Akbari, 2005: 5)

The process how green rooftops may mitigate the heat island effect and the pollutions that goes with it is illustrated in Figure 3.5. Green rooftop systems have direct and indirect benefits that oppose the heat island effect. Green rooftops directly influence and reduce the air condition use in summer. Green rooftops may reduce the outdoor temperature.

The reduced use of air conditioning leads to a lower demand at the power supply and the result is less energy consumed. The reduced outdoor temperature slows the photochemical reactions of pollutants and the result is thus less smog. The reduced outdoor temperature leads to less emission of CO_2, NO_x, and VOC Levels which results in less smog.

3.8 CREATION AND PRESERVATION OF HABITAT AND ECOLOGICAL BIODIVERSITY

Green rooftop systems may contribute to enhancement of biodiversity and conservation. Green rooftop systems provide a habitat in areas where there is limited vegetation (Grové, 2012: Online). The green rooftop system may create new links between existing areas.

Rare species may find refuge in green rooftop systems. Green rooftop systems may even provide a link for migration of plants, birds and invertebrates (Carpenter, 2014: 9). According to Oberndorfer *et al.* (2007: 829) green roofs may contribute to local habitat conservation. Studies have documented avian and invertebrate communities on a variety of green rooftop systems in several countries (Coffman, Davis, Brenneisen & Kadas in Oberndorfer *et al*., 2007: 829). Green roofs are commonly inhabited by various insects, including ants, beetles, flies, bugs, spiders, bees, leafhoppers, and beetles (Coffman & Davis in Oberndorfer *et al*., 2007: 829). Rare and uncommon spider and beetle species have been recorded on green rooftops (Brenneisen & Grant in Oberndorfer *et al*., 2007: 829). The richness of the spider and beetle species on green rooftops is positively correlated with the richness of the plant species as well as the topographic variability (Kadas in Oberndorfer *et al*., 2007: 829). According to Baumann (2005: Online) green rooftops may be used by nesting birds.

According to Van Niekerk *et al.* (2011: 10) green rooftop habitats may create green ‘stepping stones’ between fragmented open spaces in urban areas. This may encourage the movement of mobile species such as insects and birds.

Figure 3.6 compares the amount of animals spotted on a green roof and blank roof between 27 October 2010 and 2 February 2011.

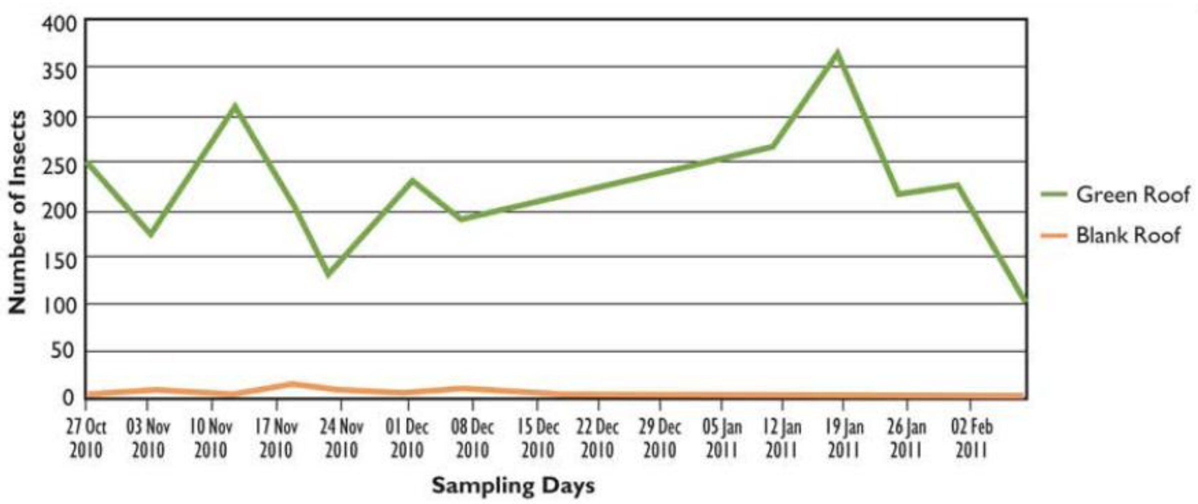

Figure 3.6 Comparison of animals spotted on a green roof and blank roof.

(Van Niekerk *et al.,* 2011: 10)

Figure 3.6 compares the number of animals spotted on a green roof and a blank roof. A total of 15 Sampling days were taken. On average 221 insects were spotted on the green roof, with the highest catch on a single day being 365 insects. In contrast, the average number of insects that were spotted on the blank roof was 2 insects with the highest catch on a single day being 11 insects. A green rooftop thus contributes to a habitat for animals.

Figure 3.7 reflects the different species of animals that were spotted on the green rooftop system.

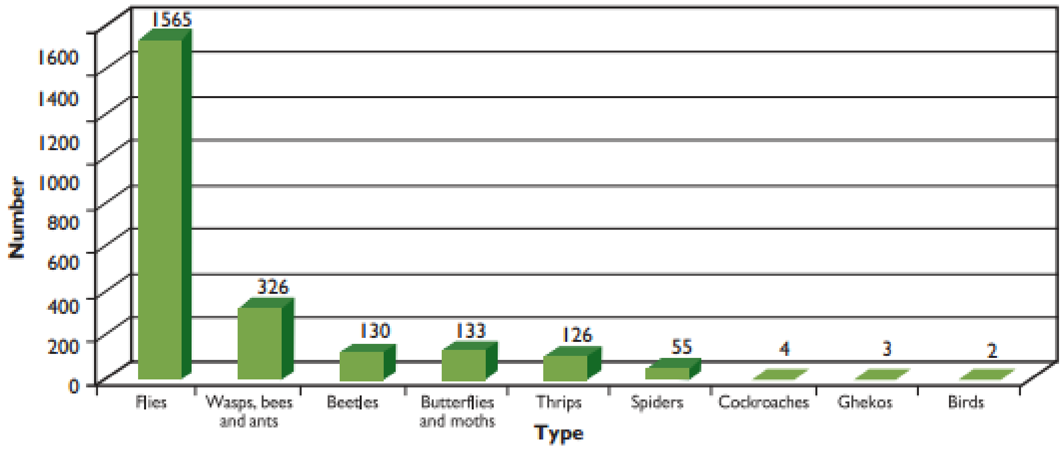

Figure 3.7: The different animal species spotted on the green rooftop system

(Van Niekerk *et al.* 2011: 10)

Figure 3.7 indicates that 2344 animals were spotted on the green rooftop system. This includes 1565 flies, 326 wasps, bees, and ants, 130 beetles, 133 butterflies, 126 thrips, 55 spiders, 4 cockroaches, 3 ghekos, and 2 birds.

According to Van Niekerk *et al.* (2011: 10) three different birds were spotted on a green rooftop in Durban, South Africa, namely the Paradise fly-catcher, White-Breasted Sunbird, and Black-eyed Bulbul.

When designing for biodiversity, the plant species, building height and food sources need to be taken into consideration. It is important to realize that plant species that have been selected primarily for stormwater management, aesthetic or human use may not be able to provide ecological diversity or a habitat. It is thus important to decide on the objectives to be gained by the green rooftop system prior to its design (Carpenter, 2014: 8).

3.9 AESTHETICS AND RECREATIONAL SPACE

Cities that are undergoing rapid population growth and building development depend on space available. Green rooftop systems may help increase the amenity, open space, food production, commercial and recreational space (Carpenter, 2014: 10).

According to Grové (2012: Online) and Carpenter (2014: 10), it has been suggested that green spaces reduce stress, reduce patient recovery time, improve worker productivity, increase property values, decrease noise, and have even been linked to a reduction in crime.

Shuanggui, Jing and Shiyuan (2011: 253) point out that the era of green urban planning aims to replace the era of mechanical reproduction. The mechanical era is seen as a depressing and boring age and the green era strives to bring more relaxed, and emotionally happy living conditions.

According to Maas (2009: Online) people living in green environments feel and are healthier. More green space surrounding the living environment results in fewer visits to the doctor with complaints such as depression, COPD, dizziness, and diabetes. People living in a green environment recover more quickly from stress. Maas (2009: Online) states that "green space is more than just a luxury product, it actively promotes health". Health records of 350,000 people across the Netherlands were studied to determine the effect of green spaces on the annual rates of 24 physical diseases. The study found that people living closer than 1km from green spaces had lower rates of the diseases, particularly anxiety disorders and depression.

Fjeld and Bonnevie (2002: Online) researched the effect of indoor plants on the well-being and health of workers. The study found that the level of complaints is significantly lower among workers that had plants on their tables in the office. The researchers argue that these results are due to a combination of the improved air quality in the office and the positive psychological effects of nature.

An American researcher, Ulrich cited in Van Niekerk *et al*. (2011: 19), looked at the effect of a view from a window has on well-being and health. Patients with a view of nature from their window had shorter post-operative hospital stays, required fewer injections of pain reducing drugs, and tended to have only minor post-surgical complications compared to the patients that looked out onto a brick wall.

According to Carpenter (2014: 10) it may be difficult to create new gardens and parks on the ground as most space has already been taken up by built infrastructure. It is, thus, important to use roofs for green spaces.

3.10 URBAN AGRICULTURE

According to Carpenter (2014: 10) urban agriculture contributes to ensuring food security, it may enhance community participation in the food system and it may even improve health. Green rooftop systems that produce food may become a community gathering place, which may provide food for local distribution, supplement a restaurant kitchen, or even be sold on a commercial scale.

According to Van Niekerk *et al.* (2011: 20) it is estimated that 15% of households in Durban do not earn enough money to pay for food. Changes in climate may exacerbate the situation as agriculture is sensitive to climate changes. This may result in increasing costs of food due to scarcity and imported food. Rooftop agriculture may contribute to local food security. Agriculture on rooftop allows people to grow their own food.

3.11 CREATING JOBS

According to Green Roofs for Healthy Cities (2014a: Online) the growth of green roofs opens up new job opportunities for local people. These job opportunities are related to manufacturing, design, plant growth, installation, and maintenance. According to Lamb (2013: Online) the vegetable green rooftop garden concept in Cape Town revolves around exploiting job-creation opportunities. This is done by recruiting homeless and unemployed people to build and maintain green roof structures, to grow and sell the vegetables to the deli's and restaurants downstairs.

3.12 SUBSIDIZING GREEN ROOFTOP SYSTEMS

According to Holzmüller (2009: Online) Düsseldorf in Germany has subsidized about 110 projects from 2000 to 2009. Düsseldorf has a population of 11 million people and is pursuing every available opportunity to boost the number of green roofs. The efforts to create more green roofs in the city became the reason why Düsseldorf has been awarded the 2008 gold medal in the Europe-wide contest 'Entente Florale'.

3.13 NATIONAL BUILDING REGULATIONS

According to Kazmierczak and Carter (2010: Online) the city of Basel in Switzerland has the highest area of green roofs per capita in the world. Since 2002, the building regulations of Basel were amended to include green roofs. This goes to show that amending building regulations might make a difference in motivating the use of green rooftops. Berry (2012: 331) concludes that documents that serve as a communication instrument in die construction industry need to be updated regularly in order to improve the industry. In this way, the entire construction industry will benefit from it.

3.14 MONEY AS A MOTIVATOR

Orando (2012: 26) concludes that money is an important motivator in human behavior. If green rooftop systems prove to be economical and to increase revenue of developments, it may serve as a motivator to include green rooftop systems in future developments. Given that developers aim to make a profit (Burger, 2013: 101), they may either choose to retain some or all of the development or to sell the entire development. Green rooftop systems may improve the profit margin.

Tsung-Hsien and Yen-Lin (cited in Orando, 2013: 89) argue that the customer drives everything in the best companies. This may be applicable to the demand in housing types. If the population living in the inner city would prefer to reside in a building with a green rooftop system and would be prepared to pay more for the option, the demand would increase. When there is a demand for green rooftop systems on buildings, developers may use the opportunity to develop accordingly.

3.15 AIR QUALITY

Cities are challenged with several problems and air quality is one of them. Air quality may be measured in order to regulate the air quality problem. Worldwide, cities measure the quality of the ambient air on a daily basis and report on it. Johannesburg is one of the cities that measure the air quality and is shown to be in a bad state. It is important to be aware of the air quality of a city in order to know if it is systematically getting worse or better and if drastic measures should be taken to combat bad air quality. This will benefit the decisions that needs to be taken for better air quality in the future or to sustain good air quality. There are several particles present in the air of busy cities and it is important to establish whether there are toxic particles present and at what level.

Rooftop gardens may be able to mitigate the polluted air. According to Jedlinski (2014: 106) the US Environmental Protection Agency criteria for measuring the effectiveness of reducing the ‘carbon footprints’ include the increase of the size of the green areas in a city.

3.15.1 Air quality index

According to AirNow (2014: Online) the air quality index (AQI) is an index for reporting air quality on a daily basis. It is a measurement which tells you how clean or polluted the air is. The air quality index indicates what level of pollution is harmful to human health and to what degree. The AQI runs on a scale form naught to five hundred (0-500). An AQI value of 50 or less represents healthy air quality. The Environmental Protection Agency (EPA) considers readings below 100 as acceptable (AirNow, 2014: Online). AQI values above 100 are considered to be unhealthy for sensitive people. As the AQI value gets higher, it becomes unhealthy for everyone.

Table 3.1 categorizes the different levels of health concern and what each level means.

Table 3.1: AQI Categories

Air Quality Index (AQI) Values	**Levels of Health Concern**	**Colours**
***When the AQI is in this range*:**	***..air quality conditions are:***	***...as symbolized by this colour:***
0-50	Good	Green
51-100	Moderate	Yellow
101-150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

(AirNow, 2014: Online)

There are six levels of health concern. Good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy and hazardous. ‘Good’ implicates an AQI level reading of 0-50. The air pollution is minimal and poses little or no risk. The air quality is considered to be satisfactory. ’Moderate’ implicates an AQI level of 51-100.

The air quality is considered to be acceptable; however, people who are unusually sensitive to ozone may be experiencing respiratory symptoms. ’Unhealthy’ implicates an AQI value of 101-150. The general public might not be affected by the quality of the air, but sensitive citizens could be affected such as the elderly, children, and people with heart and lung problems. ’Unhealthy’ implicates an AQI of 151-200. At this level, everyone might start to experience adverse health effects. ’Very unhealthy’ implicates an AQI reading of 201-300. When the AQI level is this high, it might result in a health alert where everyone may experience serious health effects. ’Hazardous’ implicates and AQI level that exceeds 300. At this level, the entire population might be effected and health emergencies may occur.

3.15.2 The air quality index of Johannesburg

According to the Economist (2013: Online), the World Health Organisation measures the total mass of particles of 10-micron diameter or smaller per cubic meters on the AQI scale. This is called PM 10. The PM 10 allows cross-country comparisons because it is widely used.

Figure 3.8 reflects the 20 most polluted cities in the world with the biggest economies by using the AQI of PM 10.

Figure 3.8: The 20 most polluted cities in the world

(Economist, 2013: Online)

Figure 3.8 is a graph that illustrates the ranking of the 20 most polluted cities in the world by using the annual average AQI of PM 10. The top 20 cities include the following:

- Ludhiana in India has an AQI annual average of 251 PM 10 and according to the scale it is the most polluted city in the world.
- Lanzhou in China has a reading of 150.
- Mexicali in Mexico is at 138
- Medan in Indonesia is at 112.
- Anyang and Bussan in South Korea are both at 68.
- Johannesburg is ranked the 7th most polluted city in the world and has a reading of 66.
- Rio de Janeiro in Brazil is 64.
- Turin in Italy is at 47.
- Seville and Zaragoza in Spain: 44
- Paris in France: 38

- Bakersfield in the USA: 37
- Montreal and Sarnia in Canada: 34
- Moscow in Russia: 33
- Dresden in Germany: 32
- London in Britain: 30
- Osaka in Japan: 28
- Brisbane in Australia: 18

Gondwana Environmental Solution (2007: 12) measured and recorded the pollutants present in the air of Johannesburg. The measurements show that Johannesburg in South Africa falls under the cities that are polluted.

Table 3.2 summarises the guidelines for the different pollutants present in the air of Johannesburg.

Table 3.2: City of Johannesburg ambient air quality guideline

Pollutant	Average Period	µg.M^{-3}
Sulphur dioxide	Annual	50
Nitrogen dioxide	Annual	40
Nitrogen Oxide	Annual	188
Oxides of nitrogen	Annual	284
PM10	Annual	40
Carbon monoxide	8 hour running average	10 000
Lead	Annual	0.5
Ozone	8 hour running average	120
PM2.5	24 hour	25
Benzene	Annual	10

(Gondwana Environmental Solution (Pty) Ltd, 2007: 12)

Gondwana Environmental Solution (Pty) Ltd (2007: 34) measured the pollutants and intensity in the ambient air of Johannesburg and compared it with the guidelines. It has been concluded that the PM10 is of the greatest concern. The PM10 concentrations are at all times exceeding the air quality guidelines. The situation is worse in the winter due to temperature inversions and calm winds, which promote the stagnations of the air pollutants. The rest of the criteria pollutants infrequently exceed the guideline.

3.15.3 THE CAUSES OF THE POOR AIR QUALITY IN JOHANNESBURG

Momberg and Grant (2008: Online) state that the air pollution levels in and around Johannesburg is worsening. According to Gondwana Environmental Solution (Pty) Ltd (2007: 8-11), four causes of the poor air quality in Johannesburg include the following:

3.15.3.1 Domestic Coal Burning

Households in the City of Johannesburg use fuels such as paraffin, coal, and wood for space heating and cooking purposes. The use of these fuels occurs especially in low-income areas that include Alexandra, Diepsloot, Orange Farm, and Soweto. The rapid growth of informal settlements has resulted in a shortage of electricity and waste removal. This is confirmed by Momberg and Grant (2008: Online).

3.15.3.2 Vehicle emission

According to British Columbia (2013: Online), vehicles emit the following: Nitrogen Oxides (NOx), Fine Particulate Matter (PM2.5), Volatile organic compounds (VOC's), Carbon Monoxide (CO), Sulphur Dioxide (SO2), Air Toxics, and Coolants (Momberg & Grant, 2008: Online) and (Enslin, [n.d.]: Online). The City of Johannesburg (2012: 20) estimates that vehicles in Johannesburg emits 6.84 million tonnes of Carbon Dioxide (CO2) per year. Vehicles thus contributes to the greenhouse gasses and poor air quality in Johannesburg.

3.15.3.3 Mining Operations

Mining operations emits fugitive dust. Particulate matter is the main pollutant. Several activities add to the situation. The activities include, drilling, blasting, truck on unpaved roads, loading and off-loading of material and storage piles and wind (Enslin, [n.d.]: Online).

3.15.3.4 Industrial Activities

The City of Johannesburg is home to large industries such as steel and iron processes, brickworks, and boiler operations. Emissions from the industrial activities include SO2, NOx, and PM (Momberg & Grant, 2008: Online).

3.15.3.5 Waste Disposal and Incineration

There are four operational landfills within the City of Johannesburg. The four landfills include Robinson Deep landfill, Marie Louise Landfill, Goudkoppies landfill and Ennerdale landfill. The impact of poor management of landfills includes air pollution (City of Johannesburg, 2009: Online).

3.15.4 Cleaning the air with vegetation

Vegetation offer the ability to remove air pollutants. Subsequently, the environmental quality and human health improves (Connelly & Hodgson, 2008: 1). Nowak, Crane and Stevens (2006: 121) estimated the percentage by which air quality may be improved due to air pollution removal by urban trees and shrubs. It has been estimated that Portland in the US has a tree cover of 42% by Nowak *et al*. (2006: 121) and the percentage air quality improvement is estimated as follows: carbon monoxide (CO) improves by 0.003%, nitrogen dioxide (NO2) may improve by 0.6%, ozone (03) may improve by 0.8%, particles of 10-micron diameter (PM10) may improve by 1% and sulphur dioxide SO_2 may improve by 0.7%. Nowak *et al*. (2006: 115) concludes that vegetation may help improve air quality for various different pollutants in cities. The existing percentage of air quality improvement due to the removal of pollutants by urban trees and shrubs are modest. However, it may be improved by increasing the urban vegetation cover.

Johannesburg specifically will benefit from green rooftop systems because of the extensive pollution caused by domestic coal burning, mining operations and waste disposal and incineration as well as the general air pollutants which is vehicle emission and industrial activities.

3.16 CONCLUSION

Green rooftop systems contribute to a buildings' energy savings. The green rooftop system acts as insulation. In summer, the green plantings on the roof shades the building from solar radiation. In winter, the growing medium provides an additional layer of insulation.

Green rooftop systems extend the life of the roof membrane. Green rooftop systems may increase the lifespan of a conventional roof by double the time, which prolongs the practical life of the roof to 20 years. Green rooftop systems block sounds partially. The growing medium may block the lower frequencies of sound and the plants may block the higher frequencies of sound. Green rooftop systems may help slow down the spread of fire to and from the building through the roof, especially where the growing medium is saturated. Green rooftops represent a strategy that contributes to the control of the runoff rainwater in urban environments. It is, thus, a viable tool for stormwater management. Green rooftops help mitigate the urban heat island effect by lessening the dark, exposed concrete surfaces and by the transpiration process.

Green rooftop systems provide a habitat in areas where there is little vegetation. The green rooftop systems create new links between existing areas. Additional habitats may be provided for rare or important species. Green rooftop systems may help increase the amenity, open space and food production. Green rooftop systems increase commercial and recreational space. It has been suggested that green spaces reduce stress, reduce patient recovery time, improve worker productivity, increase property values, decrease noise, and have even been linked to a reduction in crime. Rooftop spaces may even be used as urban agriculture space which contributes to help ensure food security. It enhances community participation in the food system and it may even improve health.

Building regulations may be amended for the benefit of green rooftop systems and healthy cities.

The air quality index (AQI) is an index for reporting air quality on a daily basis. It is a measurement which tells how clean or polluted the air is. Johannesburg is ranked the 7th most polluted city in the world and has a reading of 66 PM10. Sulphur dioxide, Nitrogen dioxide, Nitrogen Oxide, Oxides of nitrogen, PM10, Carbon monoxide, Lead, Ozone, PM2.5, and Benzene are present in the ambient air of Johannesburg. PM10 is of the greatest concern; however the rest of the pollutants do exceed the baseline at times.

The causes of highly polluted air quality in Johannesburg are domestic coal burning, vehicle emission, mining operations, industrial activities, waste disposal and incineration. Vegetation may help improve air quality for various different pollutants in cities. With a 42% tree cover in the city, the improvement of the air quality is more or less 1%. However, the greater the area of plant and tree cover, the more air may be filtered by the vegetation.

Before a green rooftop system is installed, the construction method and materials available in South Africa need to be considered as well as the factors that might be taken into account when constructing a green rooftop system. Constructing a green rooftop system using South African products and methods will be presented in the next chapter.

CHAPTER 4: CONSTRUCTING GREEN ROOFTOPS

4.1 INTRODUCTION

There are certain factors that should be considered before designing and implementing a green rooftop system. It is important to realize that each building, each site, each building owner, and each user differs. Therefore, each green rooftop system will be different in order to fulfill the different needs and criteria (Peck & Kuhn, 2003: 10). Factors like the access available, location, and climate, weight loading capacity, drainage system and professional team should all be taken into consideration when designing the green rooftop system. The step-by-step installation procedure as well as the products available in South Africa will be discussed in this chapter.

4.2 LOCATION AND CLIMATE

The location of the site and the rooftop are important factors that contribute to the design of the green rooftop system. Factors such as the height of the roof, wind exposure, the orientation of the roof to the sun, and the amount of shade due to surrounding buildings will have an impact on the design. The microclimate and the general climate of the area should be taken in consideration when designing a green rooftop system. The view to and from the rooftop will play a role in the design to obtain maximum effect (Peck & Kuhn, 2003: 10).

According to Carpenter (2014: 26), the average wind speeds are greater at higher levels than ground level. Wind may be strong around the edges of buildings. Tall buildings may cause a strong down-draft wind. When designing a green rooftop system, all wind forces need to be taken into consideration. The structure and vegetation need to be able to withstand the wind forces these will be subjected to. The temperature might be influenced by the wind shear and in turn will influence the plant selection.

The light intensity tends to be greater at higher levels than at ground level. The reason for the higher light intensity is the lack of vegetation and structures around to absorb the solar radiation. In addition, the reflection from adjoining buildings and surfaces increases the radiation. Conversely, some adjoining buildings may produce intense shading on the green rooftop (Carpenter, 2014: 26).

According to Encyclopaedia Britannica (2015: Online), the temperature in urban environments tend to increase with elevation. The increase in temperature is due to the increased thermal mass of built structures. The likely temperature range of the rooftop is crucial in the planting selection.

Hepplewhite and Witkoppen Wildflower Nursery (2013: Online) explains that any garden has multiple micro-climates, even if it is only a few square metres in size. The selection of plants for each specific area needs to correspond with each micro-climate. The correct placement of the plant species will contribute to optimal plant growth rates, minimize watering and maintenance, and decrease plant death rates. The design and selection of plants are therefore influenced by the location and climate.

Table 4.1 lists the elements which need to be taken into consideration when identifying the micro-climate zones on a rooftop.

Table 4.1: Elements to consider when identifying the micro-climate

Element	**Description**
Regional Climate	The general climate of the region needs to be taken into consideration when choosing plants for a green rooftop system. For example, winter versus summer rainfall.
Orientation	Sloped roofs that face south or west are less exposed to direct sunlight and are therefore cooler and wetter. Sloped roofs that face north or east are more exposed to direct sunlight and are therefore warmer and drier.
Wind	Plants that are situated in exposed areas on the roof may experience higher wind influence. Wind stresses plants more by increasing evaporation off their leaves, and by damaging foliage and branches.
Shading	Some areas on the roof may be subjected to shade due to adjacent buildings and/or structures. The shaded areas might be permanently or periodically shaded.

(Van Niekerk *et al.,* 2011: 22)

Table 4.1 summaries the micro-climate to consider when constructing a green rooftop system. The elements that need to be considered include regional climate, orientation, wind and shading. Regional climate is the general climate of the region and only certain plants are adapted to this climate. The vegetation needs to be chosen accordingly. The orientation involves the direction the rooftop garden is facing and whether the area gets mostly sunlight or shade. The vegetation needs to be chosen accordingly. The amount of wind that the roof is likely to get need to be considered as some species of vegetation are stressed by wind. Shading might be caused by neighboring buildings. Some vegetation might not survive in too much shade and other might thrive. The micro-climate is thus an important factor when choosing the plant types for the roof.

4.3 WEIGHT LOADING

Before planning the green rooftop layout and vegetation, the weight loading capacity needs to be known (Biello, 2014: Online). In case of a new building, the structural engineer is responsible for designing, advising on construction and determining the weight load capacity of the roof. If it is an existing building, it is the structural engineers' responsibility to determine the structural integrity of the building and whether the building needs to be modified in order to support a green rooftop system. It is possible to add structural elements like beams and columns to increase the weight loading capacity. This needs to be designed by the structural engineer (Carpenter, 2014: 27).

When designing the structure, the following loads need to be taken into consideration:

- Dead load – this includes the final weight of the structure and everything that forms part of the roof: the planting medium, plants, roof structure.
- Live load – this includes people and mobile equipment that will use the space.
- Transient load – this is any moving, rolling or short-term loads and includes wind, seismic activity and water (Miller, 2015: Online).

Table 4.2 indicates the proportional weight/m² for the different types of vegetation.

Table 4.2: Weight loading as per vegetation type

Green rooftop vegetation type	Weight loading (kg/m²)
Succulent and grasses	10.2
Perennials and low shrubs up to 1.5m	10.2-20.4
Turf	5.1
Shrubs up to 3m	30.6
Small trees up to 6m	40.8
Medium trees up to 10m	61.2
Large trees up to 15m	150

(Carpenter, 2014: 27)

Table 4.2 summarizes the load per vegetation type. Succulents and grasses may only have a weight load of 10.2kg/m². As the plant species gets bigger, they require deeper growing medium. Deeper planting medium means a heavier load/m².

Trees up to 15m high may result in a weight loading of 150kg/m². When designing a green rooftop system, the structure needs to be able to support the desired vegetation's load. The heavier the load, the more expensive the structure will be. As the design, construction and development of a green rooftop system is a complex matter, professional consultants may be needed in order to complete the job successfully.

4.4 CONSULTANTS

The consultants that will form part of the professional team depend on the function of the green rooftop system, the size of the project, the project's location, and the experience of the project instigator (Peck & Kuhn, 2003: 10). Technical knowledge and experience are essential in the built environment (Burger, 2013: 17).

- Structural engineer: the structural engineer needs to determine the loading capacity of an existing roof structure and whether the structure is able to accommodate a green rooftop system. If the roof structure is not strong enough to accommodate a green rooftop, it is the structural engineer's responsibility to design a retro-fit structure that will be able to hold the green rooftop system. In the case of a new building, the structural engineer needs to take the load of the green rooftop system into account when designing the structure.
- Civil engineer: the civil engineer will be responsible for incorporating the green rooftop drainage system with the stormwater system of the building.
- Architect: an architect may be required to do the overall design of the building and incorporate the green rooftop in the design and specify the materials that should be used.
- Landscape architect: the landscape architect will be responsible for designing the layout of the green rooftop system and to select the plants.
- Mechanical engineer: the mechanical engineer will be required to calculate the cooling and heating implications of the green rooftop and to incorporate it in the HVAC design as necessary.
- Specialist consultants may include a horticulturalist; and ecologist; biologist; a roofing consultant; an artist; and planner (Green Roofs for Healthy Cities, 2014b: Online).
- Quantity Surveyor: to determine the feasibility and cost of the project.
- Project Manager: an effective project manager needs to have project management knowledge, interpersonal knowledge, technical knowledge and experience.

According to Burger (2013: 17), a combination of these knowledge areas is needed in order to manage a project effectively and successfully.

4.5 DRAINAGE

According to the Landscaping and Landscape Development Research Society (FLL) (2002: 20), care needs to be taken from the beginning of the planning of a green rooftop system to ensure that proper drainage facilities are available from all areas, whether the area has been subjected to greening or not. There are three different drainage systems that may be used to drain excess water off the roof.

- Drainage within the vegetation area
- Drainage outside the vegetation area
- Separate drainage facilities for the green area and the area with no vegetation (FFL, 2002: 20).

If the drainage facilities are located within the vegetated area, the green roof system needs to have at least one run-off facility and one emergency overflow, regardless of the size of the roof surface. The run-off facility and emergency overflow needs to be designed according to SANS 10400 Building Regulations (2008).

According to Carpenter (2014: 28), it is important to find out whether the site has a primary and/or secondary drainage system. A primary roof drainage system may use simple waterspouts, box gutter for flat roofs, box drains built into the roof or eaves gutters for pitched roofs. The primary drainage system may consist of these collector drains that are designed to flow only when it is partly full.

Hydromax (2012: Online) explains primary and secondary drainage. A primary drainage system is not designed to remove all the water that falls on the roof during heavy rain. A green roof may thus require a separate secondary drainage system. The secondary drainage system is known as the overflow relief system. For nearly flat of flat roofs the primary drains are located at the lowest point of the roof. The secondary or overflow drains are located at a higher point on the roof. The overflow drains are designed to operate in the worst-case scenario when the primary drains are blocked and water is building up. The overflow drains remove the accumulated water and should be designed in such a way that the load of the accumulated water does not exceed the weight load capacity of the structure.

According to Carpenter (2014: 28), for roofs with a low parapet wall, overflow drainage may be achieved by flowing over the edges. To determine the necessity of an overflow relief, the expected rainfall intensity in conjunction with the existing performance of the primary drainage system needs to be considered.

Figure 4.1 illustrates the different types of drainage systems.

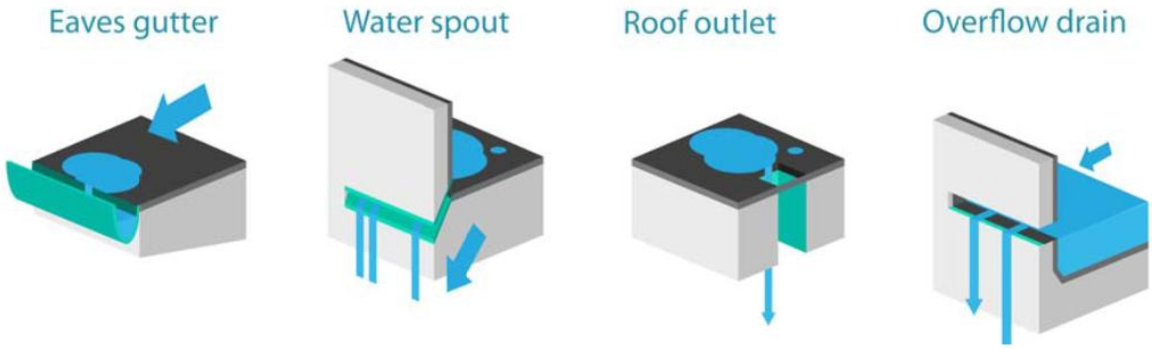

Figure 4.1: A graphic illustration of different drainage systems

(Carpenter, 2014: 28)

Figure 4.1 illustrates that an eaves gutter is a channel that has been fixed to the edge of the roof to carry water to a designated downpipe. Eaves gutters may fill up quickly in heavy rainfall. Eaves gutters alone may not be sufficient as the drainage system for a green rooftop system. It might get blocked and water may start building up. This may cause plant species to drown. However, if a gutter with a sufficient capacity is installed, it might be sufficient as the drainage system. Therefore, when designing a green rooftop system, the expected rainfall of the district needs to be taken into account as well as the amount of water produced by the irrigation system. A water spout is a hole through a parapet wall at various lowest points on the roof to discharge water from the edge of the roof. In heavy rainfall, the water spouts may struggle to discharge water quickly enough and might get blocked. A roof outlet is a hole through the roof that is situated at the lowest point on the roof. A roof outlet is mainly for flat or nearly flat roofs. An overflow drain is an example of a secondary drain. It is holes that are higher up through the parapet wall. The overflow drain discharges water once water has built up to the level of the overflow drain.

Water removal from the roof is assisted by some degree of pitch or slope. Roofs that look flat have a gentle fall to encourage movement of water into the drains. This avoids ponding. Ponding is when water dams up on a roof for extended periods of time after rainfall. Deflection of the roof structure may be caused by recurring ponding. This may cause the roof to become unstable and the drainage system may become inefficient. A pitch of at least 1.1° reduces the risk of ponding. A steeper pitch will cause the roof to drain quickly (Wijte, 2006: Online).

Figure 4.2 illustrates ponding.

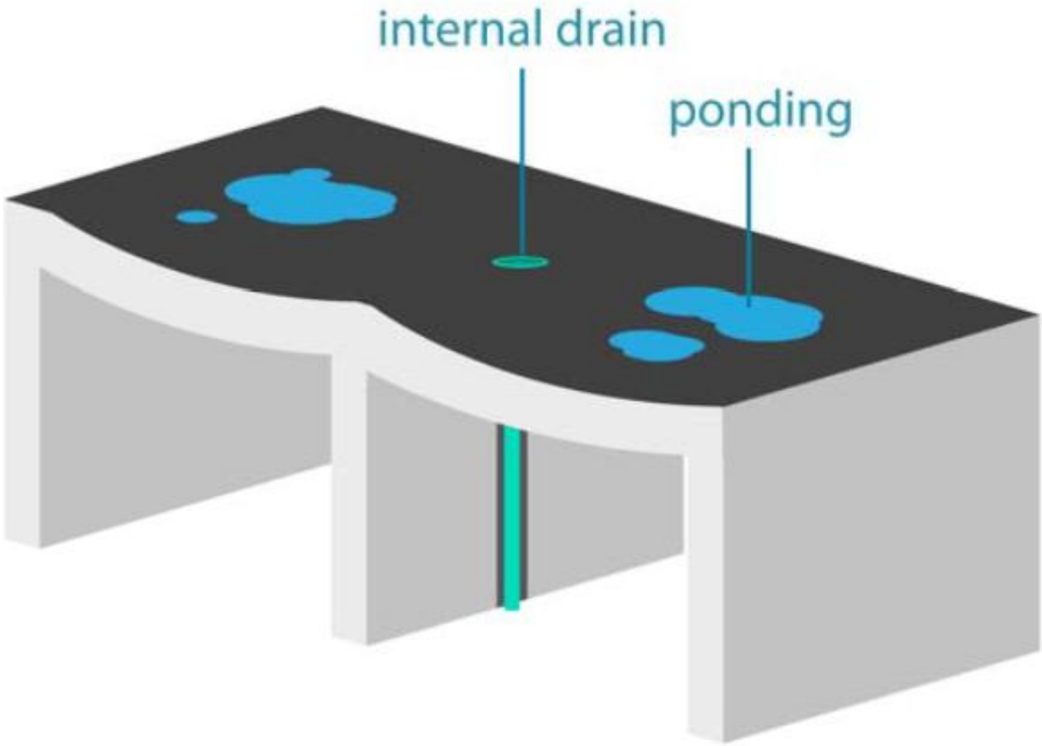

Figure 4.2: Ponding

(Carpenter, 2014: 28)

Figure 4.2 illustrates ponding on low points on the roof prevents water to flow down designated drainage systems. Ponding may cause deflection in the roof structure. To avoid ponding, the slope of the roof needs to be adjusted to direct water to a water outlet point, or a roof outlet needs to be installed at that point if possible.

According to Carpenter (2014: 28), when assessing the site designing the drainage system, the following needs to be taken into consideration:

- The amount of rainfall that lands directly on the roof.
- The amount of water that drains from an adjacent roof or wall.
- The duration of rainfall events.
- The pitch of the roof determines the speed at which the rainfall collect in the drains.
- The capacity of the drains. This includes the dimensions and diameters of the gutters and downpipes.

4.6 ACCESS

According to Peck and Kuhn (2003: 12) and Miller (2015: Online) access to the green rooftop is important for installation, ongoing maintenance and to bring up materials, soil and plants. The extensive green rooftop systems need not have access for the public, as this type of system is not for recreational purposes. The semi-intensive and intensive green rooftop systems, however, may need access for the public as it often serves the purpose of recreational space. Safe access is needed (Garden and Home, 2015: 133).

4.7 CONSTRUCTING THE DIFFERENT LAYERS WITH MATERIALS AVAILABLE IN SOUTH AFRICA

After constructing a new building with a concrete roof slab or after an existing building's concrete roof has been tested and approved for a green rooftop system, the construction of the green rooftop system may commence.

There are five layers that need to be installed in the construction of a green rooftop system. The layers consist of the following:

Layer 1: Waterproofing
Layer 2: Root Barrier
Layer 3: Drainage layer
Layer 4: Separation and additional root barrier layer
Layer 5: Growing medium

Each layer has specific materials and installation methods which is important to know.

4.7.1 Layer 1: Waterproofing

Derbigum is a waterproofing membrane that is manufactured in South Africa for South African Conditions (Derbigum Manufacturing, 2014: Online).

The roof deck needs to be to falls or cross falls of 1:80 to the outlets where water drains out. The roof deck needs to be surface dry, clean and smooth, free of protrusions, voids and contaminants. If all the requirements above are met, the surface is ready to be primed with a bituminous primer. The internal corners should be filleted and the external corners rounded (Derbigum Manufacturing, 2014: Online).

Generally, surfaces that receive a Derbigum modified-bitumen membrane need to be primed with a bitumen primer.

According to Derbigum Manufacturing (2014: Online) the specification for installing Derbigum for Horticultural purposes is as follows: “One layer Derbigum CG4H (horticultural) on one layer Derbigum CG3 waterproofing membrane, laid staggered with side laps of 100mm and end laps of 150mm, sealed to bitumen primed surfaces by torch-fusion.”

Figure 4.3 illustrates Derbigum on a roof.

Figure 4.3: Derbigum waterproofing membrane

(Perrins, 2013: Online)

Figure 4.3 illustrates installed Derbigum on an existing roof. The next step of the rooftop garden construction may proceed.

4.7.2 Layer 2: Root Barrier

An efficient and light root barrier is 250 micron (DPM) polythene sheeting. According to the supplier, Polyfast (2010: Online), the black DBM polythene sheet has a high tear resistance, great tensile strength and it is BBA approved. It is thus suitable as a resistant membrane.

The 250 micron polythene sheeting is to be loose laid on top of the waterproofing membrane with 100mm laps and sealed with a pressure-sensitive tape (Derbigum Manufacturing, 2014: Online).

Figure 4.4 illustrates black 250 micron (DPM) polythene sheeting.

Figure 4.4: Black 250 micron (DPM) polythene sheeting

(Polyfast, 2010: Online)

Figure 4.4 indicates the black 250 micron (DPM) polythene sheeting that needs to be used for step 2 in the construction of the green rooftop system.

4.7.3 Layer 3: Drainage layer

The Delta MS20P (perforated) high density polyethylene dimpled drainage layer is a product of the Waterproofing Centre. According to Waterproofing Centre (2013: Online), *Delta MS20P is perforated dimple sheeting with a high drainage capacity. It is designed for horizontal use on roof slabs, under floor slabs and for roof landscaping. The porosity makes the dimpled sheeting pervious over the whole area which provides uniform drainage of water.*

Figure 4.5 illustrates Delta MS20P (perforated) polyethylene dimpled sheeting.

Figure 4.5: Delta MS20P (perforated) polyethylene dimpled sheeting

(Waterproofing Centre, 2013: Online)

Figure 4.5 indicates the Delta MS20P (perforated) polyethylene dimpled sheeting which needs to be used for step 3 in the construction of the green rooftop system.

The dimple sheeting may be rolled out on the polythene sheeting. The dimples should be facing the surface and the cups needs to be facing up. The sheeting may be cut with a blade. To extend a sheet, two rows of dimples need to be overlapped (Waterproofing Centre, 2013: Online).

4.7.4 Layer 4: Separation and additional root barrier layer

Bidim is a nonwoven, continuous filament, needle punched, polyester geotextile. Bidim is a product of Kaytech Engineered Fabrics, a South African company. According to Van Niekerk *et al.* (2011: 26) the Bidim A2 is the best option for green rooftop systems. Bidim A2 has several favourable properties. Bidim A2 has a mass of 150g/m2, 1.6mm thick and has a penetration load of 1.8kN. Bidim A2 has a porosity percentage of 93% (Kayteck, 2013: Online).

To install Bidim, the sheet needs to be rolled on the desired surface. The entire surface dedicated to the green rooftop system needs to be covered with the Bidim. To ensure proper coverage, Bidim may be joined by one of the following methods (Kaytech, 2013: Online):

- Sufficient overlapping. Frictional resistance keep it in place.
- Sewing with polyester thread.
- Blanket stitching by sewing galvanized wire or polyester thread.
- Stapling with wire or rods.

Figure 4.6 illustrates Bidim and the four different ways to join Bidim sheets together.

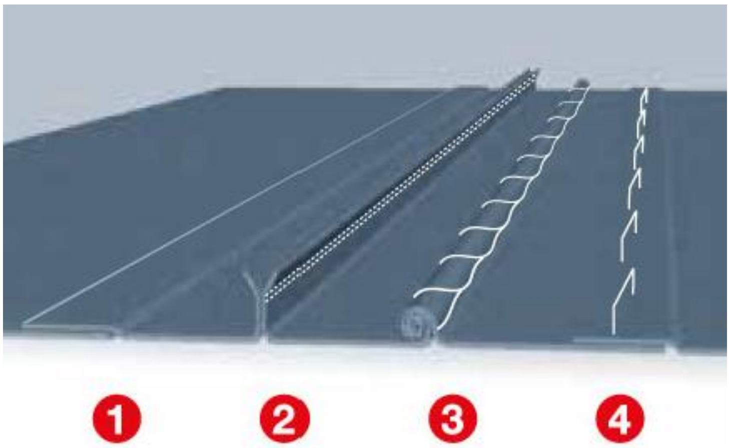

Figure 4.6: The installation of Bidim and the four joining methods

(Kayteck, 2013: Online)

Figure 4.6 Illustrates Bidim and the four joining methods:

1. Overlapping
2. Sewing with polyester thread.
3. Blanket stitching with polyester thread and galvanized wire.
4. Stapling with wire or rods

The joining method is dependent on the strength of the subgrade. If the subgrade is strong enough, the overlapping method is sufficient (Geofabrics Australia, 2009: Online).

4.7.5 Layer 5: Growing medium

The growing medium should ideally be lightweight, well-drained, and be able to retain a high degree of water without becoming waterlogged (Miller, 2015: Online). Planting media made up of materials such as perlite, expanded clay, vermiculite and volcanic rock are the best suited for green rooftop systems. The best ratio for the mix should be 60-80% inorganic materials and 20-40% organic materials (Van Niekerk *et al*., 2011: 29).

The potential inorganic media includes vermiculite, perlite, Berea red sand, dark building sand, decomposed granite, and crushed brick. Van Niekerk *et al.* (2011: 29) did a study on the mentioned growing media and concluded as follows:

- Vermiculite has a saturated weight of 178 grams per litre, which is known to be extremely light weight. The cost is reasonable and vermiculite is readily available. Unfortunately vermiculite might break down over a long period of time.

- Perlite has a saturated weight of 174 grams per litre, which is lighter than vermiculite. Perlite is the most expensive of inorganic material, but readily available. Over a long period of time, perlite might break down.
- Berea red sand has a saturated weight of 2 kilograms per litre, which is heavy if compared to vermiculite and perlite. Availability is seldom a problem.
- Dark building sand has a saturated weight of 2 kilograms per litre. The weight is the same as the Berea Red Sand and is classified as heavy. The cost is reasonable and the product is readily available.
- Decomposed granite has a saturated weight of 2 kilograms per litre, which is the same as berea building sand and dark building sand. Decomposed granite is readily available and affordable. Macro- and micro- nutrients, which are both essential for plant growth are being released as granite decomposes.
- Crushed brick has a saturated weight of 2 kilograms per litre. When the relevant machinery is not available, crushing bricks are not probable.

The potential organic media includes compost and potting mix. The characteristics of the organic media are as follows (Van Niekerk *et al.,* 2011: 29):

- Compost has a saturated weight of per 760 grams per litre and is readily available at a low cost.
- Potting mix has the same saturated weight than compost which is 760 grams per litre. Potting mix is readily available with a low cost.

According to Hickman (2013b: Online) the best growing medium mix for light weight roof systems in South Africa includes expanded perlite, expanded vermiculite and finely shredded, well-rotted bark. The mix is light weight, affordable and has a sufficient water holding capacity.

4.8 COMMUNICATION, NEGOTIATION AND PERSUASION OF IMPLEMENTATION

Communication is seen as the starting point and foundation of activities in the construction industry (Zulch, 2012: 199). Communication may thus be the key to start introducing green rooftop gardens into the construction and development community of South Africa. According to Clements and Gido (2012: 312) negotiation is the process of bargaining. The aim of the bargaining is to reach an agreement with project stakeholders or accomplish tasks.

Zulch (2012: 87) states that negotiation as a skill may be used in various stages of the communication during a project, and may be useful in reaching agreements. Thus, negotiation and persuasion might be needed to encourage green rooftop systems.

Conferences may be considered as a communication tool. A conference is defined as “an event, sometimes lasting a few days, at which there is a group of talks on a particular subject, or a meeting in which especially business matters are discussed formally” according to Cambridge Dictionaries (2015: Online). Conferences may help inform the involved parties about the ‘how to’ regarding green rooftop systems as well as the advantages and disadvantages. The involved parties may include construction contractors, landscape architects, engineers, quantity surveyors, developers and the government. If the problem is lack of knowledge, conferences might help solve the problem and help develop green rooftop systems as much as possible. Competitions might help motivate and encourage cities, or individual parties to develop proper rooftop gardens. Public buildings may be used as displays and may contribute to the persuasion to develop green rooftop systems.

4.9 PUBLIC BUILDINGS AS AN EXAMPLE FOR GREEN ROOFTOP SYSTEMS

In Vietnam, a kindergarten was built with a vegetable garden on the roof. The aim of this design was to initiate a prototype for a sustainable school design, where children may learn how to grow food (Dezeen, 2014: Online).

Figure 4.7 is a photo of the preschool in Vietnam named Farming Kindergarten.

Figure 4.7: Farming Kindergarten, Vietnam

(Dezeen, 2014: Online)

Figure 4.7 is a photo of a preschool in Vietnam featuring a vegetable garden on the roof and three protected courtyards with vegetation. Public buildings like Farming Kindergarten may be an effective way to introduce the country of the potential of green roofs.

4.10 CONCLUSION

The location and climate need to be taken into consideration when designing the rooftop garden and when deciding what types of plant species will best adapt to the location and climate. The regional climate, wind, solar radiation, temperature and shade seems to be factors to take into consideration.

It is important to know what the weight load capacity is of the structure and how heavy each layer is that will be installed in order to make sure that the weight load capacity is not exceeded. The dead weight, live weight and transient weight need to be taken into calculation.

The professional team may consist of a structural engineer, civil engineer, architect, landscape architect, mechanical engineer, horticulturalist, ecologist, biologist, a roofing consultant, an artist, planner and/or quantity surveyor. The number of different consultants that will be needed for the design and construct of the green rooftop system depends on the scope of the green rooftop garden.

The roof needs to have a primary and secondary drainage system. The primary drainage system is to drain water at the lowest points on the roof and the secondary drainage system is an overflow backup system for when the water starts to build up. Access to the roof is important for installation, ongoing maintenance and to get the material on the roof.

There are five layers that need to be constructed prior the vegetation layer. Layer one is the waterproofing layer that consists of derbigum. Layer two is the root barrier that is made out of 250 micron polythene sheeting. Layer three is the internal drainage system, which consists of Delta MS20P (perforated) polyethylene dimpled sheeting. Layer four is the separation and additional root barrier layer (the Bidim A2 geotextile) and the fifth layer is the planting medium, which should ideally be lightweight, well-drained, and be able to retain a high degree of water without becoming waterlogged. The planting medium mix should be 60-80% inorganic materials and 20-40% organic materials.

As an example, public buildings that are built with a green rooftop system, may educate the population about the possibilities of green rooftop systems. The sixth layer is plants. An in-depth study seems important, therefore in chapter 5 plant species are reviewed.

CHAPTER 5: PLANTS SUITABLE FOR GREEN ROOFS IN SOUTH AFRICA

5.1 INTRODUCTION

In order for plants to survive on rooftops, they may need to have certain characteristics. Plants need to be hardy; survive in windy conditions and full sun; and must be able to grow in shallow substrate. Plants need to survive and thrive in the local general climate; for example, winter rainfall, summer rainfall, dry winters, temperatures below freezing point, humidity, heat and severe summers. South Africa has a diverse climate and different plant species will be suitable for growing on rooftops in the different regions. According to Breuste (2004: Online), the use of indigenous vegetation for urban landscaping is a problem and not considered a priority when planning and making decisions. Indigenous vegetation needs to become an important aspect of urban biodiversity.

5.2 THE TYPES OF SPECIES THAT ARE SUITABLE FOR GROWING ON ROOFTOPS IN SOUTH AFRICA

The following plants seem to be appropriate for roofs in South Africa according to Stern and Mutshinyalo (2002: Online), Notten (2002: Online), Hankey (2009: Online), Ngalo (2010: Online), Jamieson (2002: Online), Van Jaarsveld (2005: Online), Turner (2001: Online), Malan and Notten (2005: Online), Kurzweil (2004: Online), Klopper (2007: Online), Williams, Raimondo, Crouch, Cunningham, Scott-Shaw, Lötter and Ngwenya (2008: Online), Foden and Potter (2014: Online), Snijman and Victor (2004: Online) and Mills (2013: Online).

5.2.1 Cassinopsis Ilicifolia (Hochst.)

According to Stern and Mutshinyalo (2002: Online,) the common name for Cassinopsis ilicifolia (Hochst.) is lemon thorn in English. The lemon thorn does not have an aggressive root system and may be used as a pot plant. The lemon thorn is an attractive plant due to the bright, glossy, green foliage, orange fruits and the drooping habit of the stems. The plant grows naturally in montane forest, on forest margins, along streams and in wooded kloofs in riverine bush from the southern and eastern Cape to the Eastern Free State, KwaZulu-Natal, Gauteng and Mpumalanga. The fruits are eaten by birds including starlings, barbets, pigeons, guineafowl, bulbuls, and francolins. The plant tolerates drought and frost and grows in either shade or sun (Stern & Mutshinyalo, 2002: Online). According to Petal Faire Nursery (2014: Online) the lemon thorn is a hardy, evergreen shrub which grow up to 3m high.

Figure 5.1 is a photo of the lemon thorn shrub.

Figure 5.1: Lemon thorn shrub

(Stern and Mutshinyalo, 2002: Online)

5.2.2 Eucomis autumnalis (Mill.) Chitt

According The Royal Horticultural Society (2015: Online), the common name for Eucomis autumnalis (Mill.) Chitt is autumn pineapple lily in English. The Royal Horticultural Society (2015: Online) states that the pineapple flower is a deciduous, summer-growing bulb which is generally pest and disease free. No pruning is required. The stem of the bulb grow up to 40cm and the overall height of the plant is up to 50-60cm high. Notten (2002: Online) further states that the subspecies E. Clavata grows naturally in open grassland and marshes in KwaZulu-Natal, the Eastern Free State, Gauteng, North West Province, and Mpumalanga. The pineapple plant is not difficult to grow. Once the plant is established, it does not require much attention. The plant is comfortable in full sun or partly shaded areas. The plant is dormant in die winter, but it will still tolerate winter irrigation and winter rainfall as long as the substrate is well drained. The pineapple plant is frost hardy and may survive a winter minimum of -7 ^{o}C.

Figure 5.2 is a photo of the pineapple flower.

Figure 5.2: Pineapple flower

Notten (2002: Online)

5.2.3 Portulacaria afra (Jacq.)

According to Hankey (2009: Online), the common name for Portulacaria afra (Jacq.) is porkbush in English. It is generally known as the spekboom as well. It is a popular succulent garden plant. The porkbush is an attractive, evergreen succulent shrub or small tree that reach 1.5-2m in height in a garden situation. It is a rich source of nectar for many insects. The porkbush grows naturally in warm climates on rocky slopes in succulent karoo scrub, thicket, bushveld and dry river valleys in the eastern parts of South Africa from the Eastern Cape northwards into KwaZulu-Natal, Limpopo and Mpumalanga. The porkbush is a versatile plant and may be planted in full sun or partly shaded areas. The plant grows in dry areas as well as well-watered flower beds. The bush tolerates frost to a moderate degree, especially when it is mature.

According to The Spekboom Foundation (2015: Online) the porkbush is an excellent "carbon sponge". The porkbush has the ability to absorb free carbon from the atmosphere, which is used to produce plant tissue. The porkbush is ten times more effective per hectare at carbon fixing than a rain forest. Each hectare of porkbush could capture 4.2 tons of carbon annually.

Mills (2013: Online) states that the spekboom grows primarily in the Eastern Cape and Western Cape. The spekboom grows in desert-like climates like a cactus. This means that the spekboom absorbs carbon dioxide at night. Macleod (2008: Online) explains that the spekboom has enormous carbon-storing capabilities. The spekboom has the capacity to offset harmful carbon emissions equivalent to a moist subtropical forest.

Figure 5.3 is a photo of the porkbush.

Figure 5.3: Porkbush

(Hankey, 2009: Online)

5.2.4 Aloe maculata

According to Ngalo (2010: Online) the common name for Aloe maculata is soap aloe in English. This species grows naturally from the Cape Peninsula through the Western and Eastern Cape, Eastern Free State, KwaZulu-Natal and Mpumalanga. The soap aloe prefers the milder coastal climates, yet is also found in the higher altitude of the Drakensberg.

They occur in various habitats which include rocky areas, thicket and grasslands. The flowers are a rich source of nectar and attract sunbirds.

Figure 5.4 is a photo of the soap aloe.

Figure 5.4: Soap aloe

(Ngalo, 2010: Online)

5.2.5 Aloe arborescens

According to Hankey and Notten (2004: Online) the common name for Aloe arborescens is kranz aloe in English. The kranz aloe occurs mainly over the eastern, summer rainfall areas of South Africa. It has the third widest distribution of any aloe. The kranz aloe occurs from the Cape Peninsula along the eastern coast, KwaZulu-Natal, Mpumalanga and Limpopo. The kranz aloe grows in various habitats, which include exposed ridges on mountainous areas and dense bush. The habitats stretch from sea level to mountain tops. The kranz aloe is easy to grow. The plant grows in full sun, well-drained substrate and tolerate moderate frost. It will tolerate drought and does not need maintenance once established.

Figure 5.5 is a photo of the kranz aloe.

Figure 5.5 Kranz Aloe

(Hankey & Notten, 2004: Online)

5.2.6 Asparagus densiflorus

According to Jamieson (2002: Online) the common name for Asparagus densiflorus is asparagus fern in English. Asparagus fern is a versatile perennial, evergreen plant that can be used as a container plant or ground cover. The plant grows in full sun or light shade. The asparagus fern occurs in the coastal areas in KwaZulu-Natal and the southern part of the Eastern Cape. The plants habitats include rocky areas, coastal dunes or woods. It withstands temperatures of UP to -7 ºC and it is drought tolerant. The plant grow up to 60cm high. The asparagus fern has berries which attracts birds.

Figure 5.6 is a photo of the asparagus fern.

Figure 5.6: Asparagus fern

(Jamieson, 2002: Online)

5.2.7 Aleollanthus parvifolius

According to Van Jaarsveld (2005: Online), the common name for Aleollanthus parvifolius is klipsalie in Afrikaans. The plant is a drought-tolerant succulent and it is suitable for dry bushveld and grassland gardens. The plant occurs in the northern Eastern Cape to Mpumalanga Drakensberg and surrounding area as well as the Western Cape. The klipsalie is resistant to light frost and it can re-sprout after a cold season. It thrives in containers and rockeries.

Figure 5.7 is a photo of the klipsalie.

Figure 5.7: Klipsalie

Van Jaarsveld (2005: Online)

5.2.8 Agapanthus inapertus P.Beauv.

According to Turner (2001: Online), the common name for Agapanthus inapertus is drooping agapanthus in English. The drooping agapanthus occurs naturally in grassland, forest margins through northern KwaZulu-Natal, Mpumalanga, Gauteng and the Northern Province. The habitats of the plant include mountainous, rocky areas and it is common along the Drakensberg Escarpment. The drooping agapanthus grow up to 1.5m high. The plant requires little attention once it has been established. The drooping agapanthus grows well in most soils as long as it is well drained. It thrives in full sun and the plant is relatively pest free. The plant is deciduous and it is ideal for summer rainfall, water-wise gardens. It is dormant during winter and does not require watering in this period. It could actually withstand irrigation during winter. The drooping agapanthus withstands frost.

Figure 5.8 is a photo of the drooping agapanthus.

Figure 5.8: Drooping agapanthus

(Turner, 2001: Online)

5.2.9 Crassula ovata

According to Malan and Notten (2005: Online), the common name for the Crassula ovata is jade plant in English. The plant is an evergreen shrub that grow up to 1-3m high. The jade plant occurs in the Eastern Cape and KwaZulu-Natal on rocky hillsides. The plant grows easily in loam soil as long as it is well drained. It thrives in full sun or partly shaded areas. The plant is tolerant to drought, coastal conditions and wind. It may be able to withstand temperatures as low as -1 ºC. The plant grows well in pots.

Figure 5.9 is a photo of the jade plant.

Figure 5.9: Jade plant

(Malan & Notten, 2005: Online)

5.2.10 Crassula Expansa

According to Hickman (2013c: Online) the crassula expansa is a dwarf, mat-forming succulent. The crassula expansa is drought resistant. It is, however, susceptible to attack by the mealy bug. They have shown to grow in shallow soils and to withstand extreme heat and drought. The Crassula Expansa establish themselves easily. The plant with its white flowers attract insects, in particular the honey bee. The soil needs to be properly drained, otherwise the roots will rot.

Figure 5.10 is a photo of the Crassula Expansa.

Figure 5.10: Crassula Expansa

(2013c: Online)

5.2.11 Albuca Setosa

According to Williams *et al*. (2008: Online), the common name for the albuca setosa is slymstok in Afrikaans. It is wide spread in South Africa. The provinces include the Eastern Cape, Free State, Gauteng, Kwa-Zulu Natal, Limpopo, Mpumalanga, Northern Cape, North West, and Western Cape. It occurs in rocky slopes and flats. According to the Hickman (2013a: Online) the plant is drought resistant. The soil needs to be properly drained.

Figure 5.11 is a photo of the slymstok.

Figure 5.11: Slymstok

(Williams *et al*., 2008: Online)

5.2.12 Bulbine narcissifolia

According to Klopper (2007: Online), the common name for bulbine narcissifolia is snake flower in English. The plant is hardy and does not require much attention. The plant occurs from the far eastern regions of the Western Cape, Kwa-Zulu Natal, Free State, North West, Gauteng and Limpopo. The plant is frost and drought tolerant. The plant is fast growing and prefers full sun.

Figure 5.12 is a photo of the snake flower.

Figure 5.12: Snake flower

(Klopper, 2007: Online)

5.2.13 Eulophia speciosa

According to Kurzweil (2004: Online), to grow the eulophia speciosa is easy. There are, however, certain rules that need to be strictly followed. The plant requires full sun. The eulophia speciosa occurs from the George-Knysna area through the Eastern Cape and northwards to Kwa-Zulu Natal, Mpumalanga and Limpopo.

Figure 5.13 is a photo of the Eulophia speciosa.

Figure 5.13: Eulophia Speciosa

(Kurzweil, 2004: Online)

5.2.14 Delosperma lineare

According to Burgoyne (2014a: Online), the Delosperma occurs naturally in KwaZulu-Natal. Hickman (2013f: Online) states that the delosperma lineare responds well to irrigation, yet survives extended periods of drought. The plant grows in shallow, fertile substrate. The substrate needs to be well drained.

Figure 5.14 is a photo of the Delosperma lineare.

Figure 5.14: Delosperma lineare

(Hickman, 2013f: Online)

5.2.15 Delosperma tradescantioides

The Delosperma occurs naturally in KwaZulu-Natal, Mpumalanga, and Eastern Cape (Burgoyne, 2014b: Online). According to Hickman (2013g: Online), the Delosperma tradescantioides has proven to grow on green rooftops in the Durban area. The plant survives periods of drought and grows well in shallow substrate.

Figure 5.15 is a photo of the Delosperma tradescantioides.

Figure 3.15: Delosperma tradescantioides

(Hickman, 2013g: Online)

5.2.16 Gladiolus dalenii

Ngalo (2011: Online) states that the common name for Gladiolus dalenii is african gladiolus in English. The plant grows naturally in the summer rainfall regions of the Eastern Cape north of East Londen to southern KwaZulu-Natal, from the coast to the border of Lesotho. Sunbirds are attracted to the copious nectar. It needs to be planted in full sun, in well-drained substrate. According to Hickman (2013h: Online) the plant is not particularly drought resistant; however, it is dormant in winter and requires less water then. It needs to be planted in a substrate depth of at least 100mm.

Figure 5.16 is a photo of the african gladiolus.

Figure 5.16: African Gladiolus

(Ngalo, 2011: Online)

5.2.17 Plectranthus Spicatus

The Plectranthus spicatus occurs naturally in the Eastern Cape, KwaZulu-Natal, Limpopo and Mpumalanga (Foden & Potter, 2014c: Online). According to Hickman (2013i: Online) the plant is drought resistant and has proven to grow on green rooftops in the Durban Area. The plant is one of the larval host plants used by the Gaudy Commodore Butterfly, which they readily attract. The Plectranthus spicatus, however, tends to smother other plants due to its vigorous growth and caution should be taken in this regard.

Figure 5.17 is a photo of the Plectranthus Spicatus.

Figure 5.17: Plectranthus Spicatus

Hickman (2013i: Online)

5.2.18 Cyrtanthus Sanguineus

According to Snijman and Victor (2004: Online), the Cyrtanthus Sanguineus occurs naturally in the Eastern Cape and KwaZulu-Natal. Hickman (2013e: Online) states that the Cyrtanthus Sanguineus is a medium-sized, clump-forming bulb. The plant is drought resistant and grows where there is virtually no ground cover. The Cyrtanthus Sanguineus, however, needs to be shaded by other vegetation. The plant has proven to grow in rooftop gardens in the Durban area.

Figure 5.18 is a photo of the Cyrtanthus Sanguineus.

Figure 5.18: Cyrtanthus Sanguineus

(Hickman, 2013e: Online)

5.2.19 Kalanchoe thyrsiflora

The Kalanchoe thyrisflora occurs naturally in the Free State, Gauteng, KwaZulu-Natal, Limpopo, Mpumalanga and North West (Foden & Potter, 2014b: Online). Voigt (2005: Online) states that the common name for the Kalanchoe thyrisflora is meelplakkie in Afrikaans. The Kalanchoe thyrsiflora is a succulent perennial and it does not require much attention in a sunny, dry garden.

Figure 5.19 is a photo of the Kalanchoe thyrsiflora.

Figure 5.19: Kalanchoe thyrsiflora

(Voigt, 2005: Online)

5.2.20 Cyanotis Speciosa

According to Foden and Potter (2014a: Online) the Cyanotis Speciosa grows naturally in Eastern Cape, Free State, KwaZulu-Natal, Western Cape, Limpopo, Mpumalanga, Northern Cape and North West. Hickman (2013d: Online) explains that the Cyanotis Speciosa is a low-growing, evergreen scrambling plant. The plant is drought resistant and withstand wet conditions without rotting.

Figure 5.20 is a photo of the Cyanotis Speciosa*.*

Figure 5.20: Cyanotis Speciosa

(Hickman, 2013d: Online)

The plants, lemon thorn, pineapple flower, porkbush, soap aloe, kranz aloe, klipsalie, asparagus fern, drooping agapanthus, Jade plant, crassula expansa, snake flower, slymstok, eulophia speciose, Delosperma lineare, Delosperma tradescantioides, african gladiolus, Plectranthus spicatus, Crytanthus Sanguineus, meelplakkie, Spekboom and Cyanotis Speciosa all possess the qualities to survive on roofs. Some of the plants have already proven to survive on roofs in the Durban area.

5.3 PLANTS SUITABLE FOR ROOFS IN JOHANNESBURG

According to The Local Government Handbook (2014: Online), the Johannesburg Metropolitan is the largest city in South Africa. Green rooftop systems in Johannesburg might improve the living conditions of citizens.

Table 5.1 is a summary of the plants that might be suitable for green rooftops in the City of Johannesburg.

Table 5.1: Plants suitable for green rooftop systems in Johannesburg

Scientific Name	**General Name**	**Image of Plant**
Cassinopsis Ilicifolia Hochst.	lemon thorn	
Eucomis autumnalis (Mill.) Chitt	pineapple flower	
Portulacria afra Jacq.	porkbush	
Aloe maculata	soap aloe	
Aloe arborescens	kranz aloe	
Aleollanthus parvifolius	klipsalie	
Agapanthus inapertus P.Beauv.	drooping agapanthus	
Albuca Setosa	slymstok	
Bulbine narcissifolia	snake flower	
Kalanchoe thyrsiflora	meelplakkie	
Cyanotis Speciosa	doll's powderpuff	

Table 5.1 summarizes eleven plant species that might grow and thrive on green rooftop systems in Gauteng. The plants are lemon thorn, pineapple flower, porkbush, soap aloe, kranz aloe, klipsalie, drooping agapanthus, slymstok, snake flower, meelplakkie, and doll's powderpuff. The reasons why these plants may be suitable for roofs in Gauteng is because they are indigenous to the area and have the characteristics required to survive conditions on roofs. The table includes the scientific and general known name for each plant with a photo.

5.4 CONCLUSION

Eleven species have been identified that might thrive on a green rooftop system in Gauteng. These species includes perennials, succulents and shrubs. The plants include the lemon thorn, pineapple flower, porkbush, soap aloe, kranz aloe, klipsalie, drooping agapanthus, slymstok, snake flower, meelplakkie, and doll's powderpuff. Some of the plant species have beautiful flowers. Beautiful green spaces may be developed using the appropriate plant species.

In Chapter 6, the detail of the research design and methodology used in the study is presented.

CHAPTER 6: RESEARCH DESIGN AND METHODOLOGY

6.1 INTRODUCTION

This chapter provides the detail of the research design and methodology used in the study. The research approach is explained by the research method. The methodology discusses the data collection using a control group (Burger, 2013: 159).

Green rooftop systems is a new concept to South Africa, and obstacles need to be overcome before development can take place. The obstacles need to be determined in order to be able to be eliminated.

Before the development of green rooftop systems may be encouraged, it is necessary to determine if there is a demand for it in South Africa; Is it feasible, what type of system would be the best for South Africa and what are the effects that green rooftop systems might have in South Africa?

Entering an era where green rooftop systems may be an essential part of development, it seems important to determine the level of competence and knowledge of South Africans in the construction industry regarding green rooftop systems. It is necessary to be determined and address the lack of skill and knowledge before developing green rooftop systems.

An empirical study is important to test the literature study. The following elements are tested with the empirical study:

- the familiarity of green rooftop systems of professionals in the construction industry as well as citizens of Johannesburg;
- the feasibility of green rooftop systems in South Africa;
- the factors that encourage the development of green rooftop systems;
- the benefits from green rooftop systems in the city of Johannesburg;
- the possibility of a demand for green rooftop systems in South Africa;
- how disadvantages of green rooftop systems would effect the future development thereof;
- what methods would be effective to implement in order to increase green rooftop system developments;
- what plants would be suitable for the South African weather to form part of green rooftop systems.

6.2 RESEARCH STRATEGY

Research strategy is derived from the methodological paradigm that refers to qualitative and quantitative research (Burger, 2013: 162). Qualitative research is the study of systems by interacting with and observing the involved participating elements. The emphasis is on the quality and depth of the information and not the scope or breadth of the information provided by quantitative research (Maree, 2007: 51). Quantitative research is a process that is systematic and objective in the ways of using numerical data from only a selected subgroup of a population to generalise the findings to the population that is being studied (Maree, 2007: 145). The research includes both quantitative and qualitative method to determine the perspective of green rooftop systems in South Africa. The qualitative research involved field notes. Certain observations have been made and deductions have been derived at. The quantitative research was done by means of questionnaires. From the questionnaires, data were gathered, analysed and statistics compiled. Therefore the qualitative and quantitative methods are applied to test the literature information empirically.

6.3 METHODOLOGY

The methods used to gather data include the use of books, internet websites, articles, research papers and scientific journals for the literature study. The tools used to obtain the resources are the library and the internet.

The empirical data were gathered by means of field notes and questionnaires. Questionnaires were sent out to the individuals working in the built environment to obtain expert opinions as well as to citizens of Johannesburg in order to obtain the view and perspective of the general population regarding green rooftop systems.

6.3.1 Questionnaire survey

The questionnaire group consists of quantity surveyors, architects, engineers, contractors and citizens of Johannesburg. Quantity surveying is the main focus and therefore more quantity surveyors were approached than other professional members. The questionnaires were sent out electronically via email in 2015. The questionnaires received were analysed and transformed into statistics in order to do comparisons and draw conclusions. The respondents who received questionnaire received a phone call after two weeks to inform them of the importance of their reply to the study. The opinions and knowledge of the respondents, gathered by means of questionnaires, are used to determine the general skill set for the installation and construction of green rooftop systems in South Africa and how green rooftop systems may contribute to a healthier South Africa.

Several of the questions has a Likert scale from 1 – 5 in order to indicate to what degree the respondents agree or disagree with the specific question/statement. The scale indicates the following:

1 – strongly disagree

2 – disagree

3 – neutral

4 – agree

5 – strongly agree

6.3.2 Field notes

When observing a setting, field notes are created by the researcher to remember and record the features of the setting being observed. Field notes are meant to be analysed by the researcher to produce meaning and an understanding of the situation or phenomenon being studied (Cohen & Crabtree, 2008: Online). Field notes were taken and forms part of the research. The data collected from the field notes are analysed. The data are carefully scrutinised and organised in order to reveal patterns, do comparisons and draw conclusions. The field notes used in this project involved the investigation of existing green rooftop systems in Johannesburg and existing roofs in Johannesburg with the potential for green rooftop systems.

6.4 CONCLUSION

This study was undertaken using a systematic process of collecting and interpreting data in order to make deductions and conclusions of green rooftop systems in South Africa. The research data was collected by quantitative and qualitative methods. Field notes were taken as the qualitative method and questionnaires were sent out as the quantitative method to obtain expert opinions as well as to citizens of Johannesburg in order to obtain the view and perspective of the general population regarding green rooftop systems. The data provide the information needed to be able to make deductions. The field notes were taken form the observation of existing green rooftop systems in Johannesburg CBD area and existing roofs in Johannesburg with the potential for green rooftop systems.

The research findings from the field notes are presented in chapter 7.

CHAPTER 7: FIELD NOTES - ROOFS IN JOHANNESBURG

7.1 INTRODUCTION

Rooftops in Johannesburg were investigated and analysed to find green rooftop systems and potential rooftops for green rooftop systems.

7.2 ROOFS IN JOHANNESBURG CBD

There is potential for green rooftop systems in Johannesburg CBD. Figure 7.1 is a photo taken from a skyscraper in Johannesburg CBD, which indicates the roofs of the surrounding buildings.

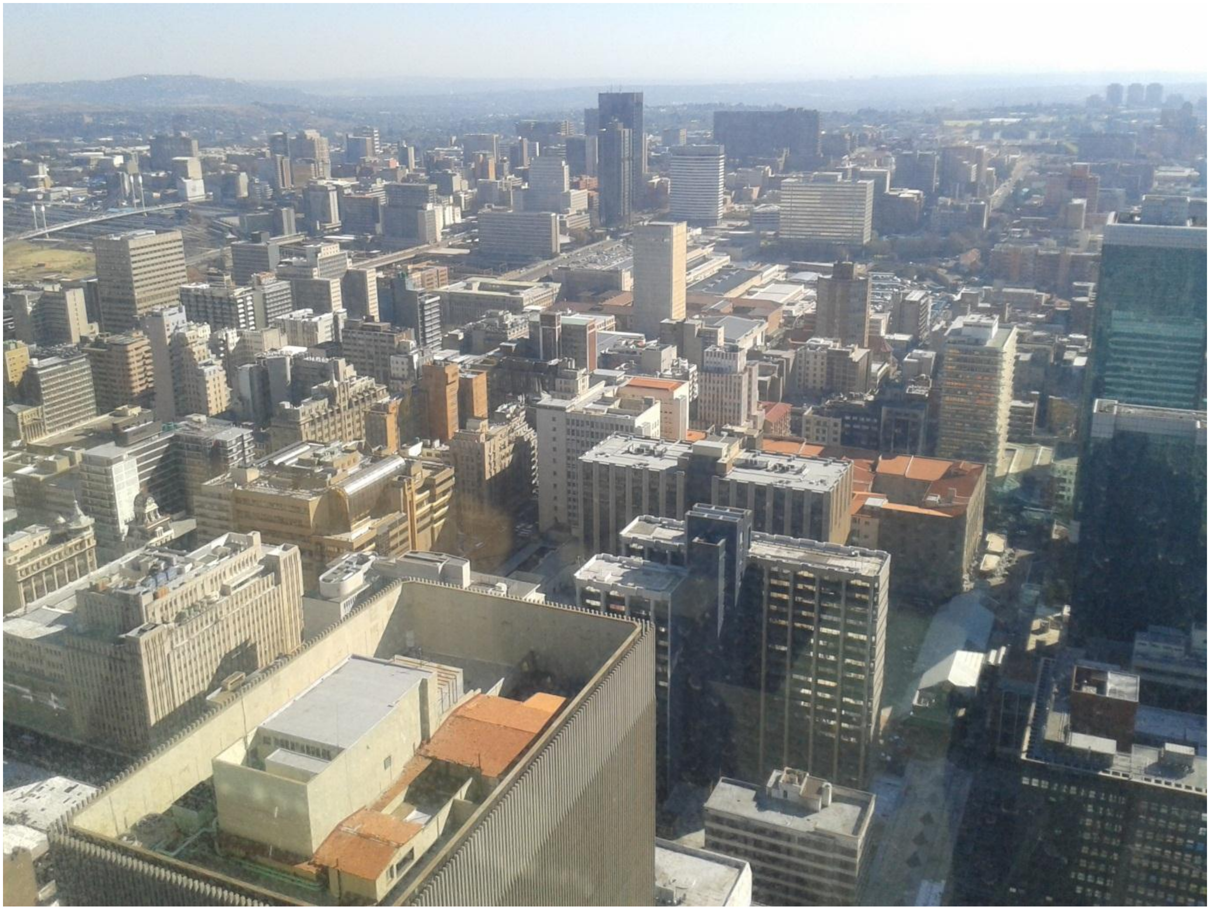

Figure 7.1: Roofs of buildings in Johannesburg CBD

Figure 7.1 illustrates that there are multiple roofs in Johannesburg CBD with the potential for the development of green rooftop systems. As the photo illustrates, there are no green rooftop systems visible, therefore it seems that there is no attention to the development of green rooftop systems in the Johannesburg CBD area from professionals in the built environment to develop green rooftop systems. Thus the deduction may be made that the benefits of green rooftop systems are ignored or unknown.

7.3 GREEN ROOFTOP SYSTEMS IN JOHANNESBURG

The only green rooftop systems found in Johannesburg are analysed. Three rooftop systems in Sandton, a financial hub, form part of the field notes as well as a house in the suburbs. The commercial buildings with the green rooftop systems in Sandton are:

- DaVinci Hotel
- The Michelanglo
- Sandton Convention Centre

The only residential house found to be investigated is in the western suburbs of Johannesburg.

- House in western suburb of Johannesburg

The first analysis of a green rooftop system is the DaVinci Hotel.

Figure 7.2 is a photo of a green rooftop system on the DaVinci Hotel, indicating a green rooftop system in the form of planter boxes.

Figure 7.2: Planter boxes on the DaVinci Hotel

The photo of a green rooftop system in Figure 7.2 is on the roof of the DaVinci Hotel. Various planter boxes have been built and filled with growing medium (compost).

The vegetation consists out of flax plant species, cycads, hen-and-chickens, other shrubs and small trees. Sprinklers are used to water the plants. The planter boxes form part of the relaxation area of the roof.

Figure 7.3 is a photo of a green rooftop system on the DaVinci Hotel illustrating the open space and relaxing area amongst the plants.

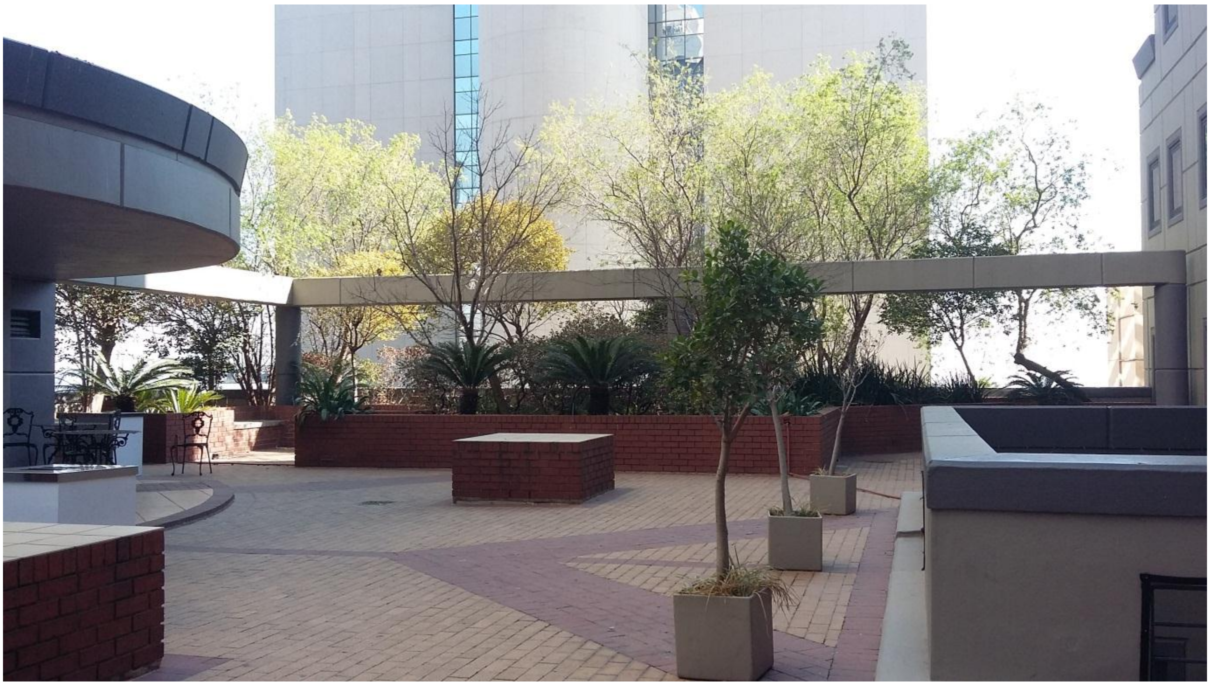

Figure 7.3: Relaxing space with green rooftop system on the DaVinci Hotel

The photo of a green rooftop system in Figure 7.3 is on the roof of the DaVinci Hotel. Instead of the entire roof made into a green rooftop system, various planter boxes have been built and open spaces are present to utilise for relaxation purposes.

The second analysis is the green rooftop system on The Michealangelo hotel.

Figure 7.4 is a photo of a green rooftop system on The Michealangelo hotel.

Figure 7.4: Green rooftop system on The Michealangelo hotel

The green rooftop system in Figure 7.4 is a photo of the roof of the The Michealangelo hotel. Instead of the entire roof made into a green rooftop systems, various planter boxes have been built and filled with growing medium and loose-standing pot plants. The vegetation consists out of shrubs and small trees. Sprinklers are used to water the plants. The planter boxes form part of the relaxation area of the roof that provide the advantage to working people to relax and take a break from work. The DaVinci Hotel and The Michealangelo have similar green rooftop systems. Both have planter boxes with vegetation, which is mainly shrubs and small trees and open spaces to use for relaxing.

The third roof that is investigated is the Sandton Convention Centre.

Figure 7.5 is a photo of a green rooftop system on the Sandton Convention Centre.

Figure 7.5: Green rooftop system on the Sandton Convention Centre

The green rooftop system as illustrated in a photo of the Sandton Convention Centre in Figure 7.5 is a green rooftop system on the roof and side of the building. The vegetation consists out of flax species plants, other shrubs and small palm trees. The planter boxes are not accessible to the public and are there for aesthetic reasons.

The DaVinci Hotel and The Michealangelo have green rooftop systems on the roofs and is paired with relaxing space for individuals. Sandton Convention Centre has vegetation on the side of the building and is for aesthetic purposes and not accessible to the public. The three rooftop systems investigated are all semi-intensive green rooftop systems, but not in its entirety, as only sections of the roofs are covered with vegetation.

The residential house investigated is in the western suburbs of Johannesburg.

Figure 7.6 is a photo of a house in the western suburbs of Johannesburg with an extensive green rooftop system.

Figure 7.6: Rooftop system on a residential house

The green rooftop system of the photo, Figure 7.6, is an extensive green rooftop system of a house. Part of the roof has been transformed into an extensive green rooftop system. The vegetation is of grass which requires low maintenance. The roof is not accessible for recreational or relaxation purposes.

Not only commercial buildings have green rooftop systems, but residential houses as well.

7.4 CONCLUSION

Field notes have been taken by observing three buildings in Sandton, Johannesburg with green rooftop systems. The green rooftop systems are in the form of big planter boxes filled with growing medium. The planter boxes are vegetated with shrubs and small trees, with loose standing pot plants. The DaVinci Hotel and The Michealangelo use the vegetated space for recreational space and relaxing space. Sandton Convention Centre has the vegetation on the side of the building and is for aesthetic reasons and is not accessible to the public. The three commercial buildings investigated are all in Sandton which is a financial hub. This indicates that green rooftop systems feature in affluent areas.

Houses do not normally have green rooftop systems installed. There is a house in the western suburbs of Johannesburg with an extensive green rooftop system. The western suburbs of Johannesburg is an affluent area and therefore has the finances to install a green rooftop system.

There are multiple roofs as illustrated in figure 7.1 with the potential for green rooftop systems in Johannesburg CBD. From the highest skyscraper in Johannesburg CBD, multiple roofs are visible; however, none of the roofs have green rooftop systems.

In the next chapter, the perspectives of South Africans regarding green rooftop systems are explored and analysed by means of empirical results.

CHAPTER 8: EMPIRICAL STUDY IN GREEN ROOFTOP SYSTEMS IN SOUTH AFRICA

8.1 INTRODUCTION

Questionnaires were sent out as the quantitative method to test the literature study.

8.2 EMPIRICAL DATA

The empirical data are presented in five parts. Firstly, the profile of respondents, followed by sections 1 to 4, the South African perspective on green rooftop systems.

8.2.1 Profile of respondents

The questionnaires were sent to practising quantity surveyors, architects, engineers, contractors and citizens in Johannesburg, South Africa.

The questionnaire were circulated to practising quantity surveyors, architects, engineers and contractors in the construction industry as well as citizens of Johannesburg by means of emails in order to determine the perspective of professionals and the public on green rooftop systems. Johannesburg was chosen because it is the financial hub of South Africa and seems to be in the forefront of development.

Table 8.1 indicates the various responding groups which consist of practising professionals in the construction industry and citizens of Johannesburg. Column 1 indicates the profession of respondents; column 2 the number of questionnaires sent out to the respective groups; column 3 the number of questionnaires received back; column 4 the percentage of responses.

Table 8.1: Profile of respondents

Responding groups	Questionnaires sent out	Questionnaires received back	Percentage
Contractors	2	2	100.00%
Quantity Surveyors	34	20	58.82%
Engineers	6	3	50.00%
Architects	7	3	42.86%
Citizens	110	40	36.36%
Total	**159**	**68**	**42.77%**

A total of 159 questionnaires were sent out. The response rate is 42.77% based on the questionnaires and is for the purpose of this study regarded as representative of the population. The response is as follows; 100% of the contractors, 58.82% of quantity surveyors, 50% of engineers, 42.85% of architects and 36.36% of the citizens answered the questionnaire. It is significant in respect of the reliability of the respons rate that 58.82% of the responses received were from quantity surveyors. However, the responses from the contractors did not distort the data.

The quantity surveyors are seen as important respondents to this study because they give the professional opinions to the developers regarding cost and feasibility of developments. The response from the citizens are deemed important because these are needed to determine the demand and view from citizens about green rooftop systems.

8.2.2 Section 1 Empirical Data

Section 1 consists of 4 questions regarding green rooftop systems in South Africa. The opinions of respondents were collected using a Likert scale of 1 to 5, where 1 is strongly disagree and 5 is strongly agree. 'None' represents the 'not respond to the question'.

The purpose of the first 3 questions in section 1 were to determine the familiarity of green rooftop systems amongst professionals in the construction industry and citizens. The aim of the question was to determine if there is a lack of knowledge in the construction industry regarding green rooftop systems.

The result of the respondents regarding the familiarity of the concept of green rooftop systems are presented in table 8.2. Column 1 lists the various responding groups, column 2 reflects the none-responses, column 3 indicates the number of responses that are not familiar with the concept of green rooftop systems, column 4 indicates the number that are familiar and column 5 gives the percentage of the responses that are familiar with the concept of green rooftop systems.

Table 8.2: Familiarity with green rooftop systems (Question 1.1)

Familiarity with green rooftop systems	**None**	**No**	**Yes**	**%**
Architects	0	0	3	100.00%
Contractors	0	0	2	100.00%
Citizens	1	6	33	82.50%
Engineers	0	1	2	66.67%
Quantity Surveyors	0	9	11	55.00%
Total	**1**	**16**	**51**	**68**
Percentage of total	**1.47%**	**23.53%**	**75.00%**	

The data analysed regarding the familiarity of green rooftop systems indicate that 75.00% of the group were familiar with the concept of green rooftop systems and that 23.52% were not familiar with the concept. What is noteworthy, is that 82.50% of the citizens were familiar with the concept. What is concerning is that 55% of the quantity surveyors were familiar with the concept; 100% of the architects; 100% of the contractors and 66.67% of the engineers were familiar with the concept of green rooftop systems.

The data clearly indicate that citizens are familiar with the concept of green rooftop systems; however, the professionals are not that familiar. Therefore, the professional members do not recommend green rooftop systems to be built and that contributes to why there are only a few green rooftop systems in South Africa. This indicates that green rooftop systems are a relatively new concept in South Africa and need to be introduced to the citizens and construction industry.

The results of question 1.2 regarding how many of the respondents have seen a green rooftop system in South Africa, indicate that 100% of the contractors had seen green rooftop systems and 66.67% of the architects had seen it. However, only 40% of the quantity surveyors, 37.50% of citizens and 33.33% of engineers had seen it. The citizens and engineers are familiar with the concept of green rooftop systems, but few had seen it. The architects and contractors were familiar with the concept and had seen it. Quantity surveyors however, were not familiar with the concept and only a few had seen green rooftop systems. The data clearly indicate why there are only a few green rooftop system developments in Johannesburg, because of the lack of knowledge of the professional team. Green rooftop systems are not well known or seen in South Africa, as 57.35% of the respondents had never seen a green rooftop system in South Africa.

In question 1.3 locations were given and divided into the nine provinces of South Africa. The provinces are Gauteng, Western Cape, Kwa-Zulu Natal, Free State, Eastern Cape, Northern Cape, North West, Limpopo and Mpumalanga. The results of Question 1.3 indicate the provinces were the respondents had seen green rooftop systems.

The purpose of question 1.3 is to determine if citizens of Johannesburg had seen any green rooftop systems in other provinces in South Africa and where. The data indicate that 36.76% of the respondents had seen a green rooftop system in Gauteng; 10.29% in Western Cape; 1.47% in KwaZulu Natal; and 1.47% in Northern Cape; and 0% in the remaining provinces.

The data gathered indicates, that green rooftop systems are widespread in South Africa and occurs in Gauteng, Western Cape, Kwa-Zulu Natal and Northern Cape. Just over half of the respondents, 57.35%, had not seen a green rooftop system, before which indicates that the existing green rooftop systems are sparsely found and relatively unknown.

The type of green rooftop system that is feasible for South African circumstances was analysed next (question 1.4).

There are different types of green rooftop systems. The three types of green rooftop systems that are analysed in the study are the extensive system, semi-intensive system and intensive system. Each system has different characteristics, therefore it is important to determine which system would be the most appropriate for South African circumstances.

The purpose of this question was to determine which type of green rooftop system is the most feasible of the types for Johannesburg as such.

The data of the extensive green rooftop system are as follows. The result of the respondents regarding the extensive green rooftop system in South Africa are presented in table 8.3. Column 1 lists the various responding groups; column 2 to 6 depicts the rating of the responses; 1 is strongly disagree; and 5 is strongly agree. Column 7 is the none-responses; column 8 is the total responses; column 9 is the average responses; and column 10 gives the ranking.

Table 8.3: Extensive green rooftop system in South Africa

Extensive	Rating 1 = strongly disagree 5 = strongly agree					None	Total	Average	Ranking
	1	2	3	4	5				
Citizens	4	3	9	9	14	1	40	3.67	1
Quantity Surveyors	5	3	3	4	5	0	20	3.05	2
Engineers	1	1	1	0	0	0	3	2.00	3
Contractors	1	0	1	0	0	0	2	2.00	3
Architects	2	0	1	0	0	0	3	1.67	4
Total	**13**	**7**	**15**	**13**	**19**	**1**	**68**	**3.27**	
Percentage of Tot	**19.12%**	**10.29%**	**22.06%**	**19.12%**	**27.94%**	**1.47%**	**100.00%**		

The data analysed indicate that the average of the respondents' opinion is 3.27; that is according to the Likert scale, between 'neutral' and 'agree' for the extensive green rooftop system in South Africa. The results are citizens (3.67), quantity surveyors (3.05), engineers (2.00), contractors (2.00) and architects (1.67). The citizens and quantity surveyors are ranked first and second with 3.67 and 3.05 respectively. The architects disagreed (1.67) and are ranked the lowest with the extensive green rooftop system being appropriate for South African circumstances. Thus, the citizens and quantity surveyors regarded the extensive green rooftop system to be feasible for South African circumstances. .

The data regarding the semi-intensive green rooftop system were also analysed.

The results of the respondents’ answers regarding the semi-intensive green rooftop system in South Africa are given in table 8.4. Column 1 lists the various responding groups; columns 2 to 6 depict the rating of the responses, where 1 is strongly disagree and 5 is strongly agree. Column 7 reflect the none-responses, column 8 the total responses, column 9 the average responses and column 10 the ranking.

Table 8.4: Semi-Intensive green rooftop system in South Africa

Semi-Intensive	Rating 1 = strongly disagree 5 = strongly agree					None	Total	Average	Ranking
	1	2	3	4	5				
Contractors	0	0	0	1	1	0	2	4.50	1
Engineers	0	0	1	1	1	0	3	4.00	2
Citizens	1	2	17	12	7	1	40	3.56	3
Quantity Surveyors	1	1	8	8	2	0	20	3.45	4
Architects	1	0	1	0	1	0	3	3.00	5
Total	**3**	**3**	**27**	**22**	**12**	**1**	**68**	**3.55**	
Percentage of Tot	**4.41%**	**4.41%**	**39.71%**	**32.35%**	**17.65%**	**1.47%**	**100.00%**		

The data analysed indicate that the average of the respondents’ opinions is 3.55; that is according to the Likert scale between ‘neutral’ and ‘agree’ for the semi-intensive green rooftop system in South Africa. The results are contractors (4.50), engineers (4.00), citizens (3.56), quantity surveyors (3.45) and architects (3.00). The engineers and contractors are ranked first and second and the architects are ranked the lowest.

Although the averages of the groups differs, the general tendency is that semi-intensive green rooftop systems represent a feasible type of green rooftop system for South African circumstances.

The data of the intensive green rooftop system were analysed as well.

The results of the respondents’ views regarding the intensive green rooftop system in South Africa is illustrated in table 8.5. Column 1 lists the various responding groups; column 2 to 6 depict the rating of the responses, where 1 is strongly disagree and 5 is strongly agree. Column 7 reflects the none-responses, column 8 total responses, column 9 average responses and column 10 the ranking.

Table 8.5: Intensive green rooftop system in South Africa

Intensive	Rating 1 = strongly disagree 5 = strongly agree					None	Total	Average	Ranking
	1	2	3	4	5				
Engineers	1	0	0	0	2	0	3	3.67	1
Contractors	0	0	2	0	0	0	2	3.00	2
Citizens	12	8	9	6	4	1	40	2.54	3
Quantity Surveyors	6	8	5	1	0	0	20	2.05	4
Architects	2	0	1	0	0	0	3	1.67	5
Total	**21**	**16**	**17**	**7**	**6**	**1**	**68**	**2.42**	
Percentage of Tot	**30.88%**	**23.53%**	**25.00%**	**10.29%**	**8.82%**	**1.47%**	**100.00%**		

The data analysed indicate that the average of the respondents' opinions is 2.42; that is, according to the Likert scale between 'disagree' and 'neutral' for the intensive green rooftop system in South Africa. The results are engineers (3.67), contractors (3.00), citizens (2.54), quantity surveyors (2.05) and architects (1.67). The contractors and engineers are ranked first and second and are neutral about the feasibility of the intensive green rooftop system and the architects' opinion is that it is not feasible and is ranked the lowest.

The comparison of the the three types of green rooftop systems, i.e. extensive, semi-intensive and intensive system, is presented in table 8.6. Column 1 lists the type of green rooftop systems, column 2 presents the citizens, column 3 presents the quantity surveyors, column 4 presents the engineers, column 5 presents the architects, column 6 presents the contractors, column 7 reflects the average of the four professional groups and citizens, column 8 reflects the percentage and column 9 the ranking.

Table 8.6: Comparison of type of green rooftop systems

Comparison of the types of Rooftop Systems	Citizens	QS	Eng.	Arch	Con.	Average	%	Ranking
Semi-Intensive	3.56	3.45	4.00	3.00	4.50	**3.55**	71.04%	1
Extensive	3.67	3.05	2.00	1.67	2.00	**3.27**	65.37%	2
Intensive	2.54	2.05	3.67	1.67	3.00	**2.42**	48.36%	3

The data regarding the comparison of the three types indicate that the semi-intensive green rooftop system is ranked 1st as a feasible type of green rooftop system, the extensive green rooftop system is ranked 2nd and the intensive green rooftop system is ranked 3rd. The contractors (4.50) felt the strongest about the semi-intensive green rooftop system being the most feasible type of system for South Africa. The citizens' (3.67) responses indicate that extensive green rooftop system is the most feasible type of system for South Africa and the engineers (3.67) were of the opinion that the intensive green rooftop system is feasible for South Africa.

The semi-intensive green rooftop system is the most feasible for South African circumstances of the three types of systems. The extensive green rooftop system may also be considered, but the intensive green rooftop system is not feasible according to the results.

8.2.3 Section 2 Empirical Data

Section 2 consists of nine questions regarding the effects of green rooftop systems in cities. The opinions of respondents were collected using a Likert scale of 1 to 5 where 1 is strongly disagree and 5 is strongly agree. The opinions of the different professions and citizens were analysed separately and in combination and both the combined data and separate data are the same; thus the data of the different professions did not distort the results.

There were 4 purposes with the questions in section 2. Purpose one was to determine which factors or effects that green rooftop systems have on the surroundings in cities will encourage the development of green rooftop systems. The second purpose was to determine what factors will bo of benefit to Johannesburg as city. The third purpose is to determine the level of appreciation and utilization of existing open parks in Johannesburg and the forth purpose was to determine if there is a demand for green rooftop systems in Johannesburg.

The combination of the results regarding the different factors influencing the development of green rooftop systems is given in table 8.7. Column 1 lists various elements encouraging development, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.7: Factors influencing the development of green rooftop systems

Elements encouraging development	Average	%	Ranking
Improved air quality	4.04	80.88%	1
Aesthetics	3.96	79.12%	2
Recreational space	3.90	77.94%	3
Habitats	3.82	76.47%	4
Job creation	3.76	75.29%	5
Heat Island effect	3.75	75.00%	6
Increasing property value	3.68	73.53%	7
Storm water management	3.68	73.53%	7
Insulation	3.62	72.35%	8
Agriculture	3.47	69.41%	9
Secure and safe	3.35	67.06%	10
Demand	3.34	66.76%	11
Sound Insulation	3.33	66.60%	12
Identity	3.18	63.53%	13
Privacy	3.04	60.88%	14
Life extention of roof membrane	3.03	60.59%	15
Belonging	2.99	59.71%	16
Memory	2.91	58.24%	17

The results indicate that improved air quality (80.88%) is ranked first, aesthetics (79.12%) is ranked second, recreational space (77.94%) is ranked third, habitats (76.47%) fourth, job creation (75.29%) fifth, heat island effect (75.00%) sixth, increasing property value (73.53%) and storm water management (73.53%) seventh, insulation (72.35%) eighth, agriculture (69.41%) ninth, secure and safe (67.06%) tenth, demand (66.76%) eleventh, sound insulation (63.53%) twelfth, identity (60.88%) thirteenth, privacy (60.59%) fourteenth, life extension of roof membrane (60.88%) fifteenth, belonging (59.71%) sixteenth and memory (58.24%) last.

Improved air quality emerged as an important factor that may encourage the development of green rooftop systems. The second to fifth important factors are aesthetics, recreational space, habitats and job creation, which may encourage the development of green rooftop systems.

Heat island effect, increasing property value, storm water management and insulation are factors that may encourage the development of green rooftop system, but to a lesser extent. Agriculture, secure and safe, demand, sound insulation, identity, privacy, life extension of roof membrane, belonging and memory are factors that are seen as less important and do not seem to encourage green rooftop systems as such.

The combination of the results regarding the different factors influencing the development of green rooftop systems is illustrated in table 8.8. Column 1 lists various advantages of green rooftop systems that Johannesburg may benefit from, column 2 presents the average, column 3 reflects the percentage and column 4 the ranking.

Table 8.8: Elements benefitting Johannesburg

Elements benefitting Johannesburg	Average	%	Ranking
Improved air quality	4.21	84.12%	1
Insulation	4.09	81.76%	2
Job creation	3.96	79.12%	3
Aesthetics	3.79	75.88%	4
Heat island effect	3.76	75.29%	5
Storm water management	3.75	75.00%	6
Economic Growth	3.75	75.00%	6
Increasing property value	3.74	74.71%	7
Recreational space	3.72	74.41%	8
Habitats	3.68	73.53%	9
Sound insulation	3.63	72.65%	10
Life extention of roof membrane	3.53	70.59%	11
Agriculture	3.51	70.29%	12
Secure and safe	3.49	69.71%	13
Privacy	3.28	65.59%	14

The data analysed indicate that improved air quality (84.12%) is ranked first, insulation (81.76%) second, job creation (79.12%) third, aesthetics (75.88%) fourth, heat island effect (75.29%) fifth, storm water management (75.00%) and economic growth (75.00%) sixth, increased property value (74.71%) seventh, recreational space (74.41%) eighth, habitats (73.53%) ninth, sound insulation (72.65%) tenth, life extension of roof membrane (70.59%) eleventh, agriculture (70.29%) twelve, secure and safe (69.71%) thirteenth and privacy (65.59%) fourteenth.

It seems that Johannesburg may benefit the most from the improved air quality offered by green rooftop systems. The elements that stand out from which Johannesburg will benefit is improved air quality, better insulated buildings, job creation, aesthetics, eliminating the heat island effect, stormwater management and economic growth. Increased property value, recreational space, habitats, sound insulation, life extension of roof membrane and agriculture are elements which Johannesburg may benefit from; however, to a lesser extent than the top five elements. Secure and safe area and privacy are less important factors for Johannesburg according to the results.

The results of table 8.7 and table 8.8 in conjunction provide important results that may contribute to finding the relevant elements to Johannesburg as such. Improved air quality, job creation and aesthetics are three elements that encourage the development of green rooftop systems as well as being beneficial to Johannesburg. Thus, the three elements may be regarded as the components that may encourage professionals and citizens to develop green rooftop systems in the Johannesburg area.

Question 2.3 determined how many of the respondents live or work within a close proximity (1km) of a green area. The purpose of question 2.3 was to determine how far the respondents live or work from green areas. According to the data, 73.53% of the respondents live or work within 1km from a green area and 26.47% do not; thus, mostly the respondents do have access to green areas.

The purpose of Question 2.4 was to determine the level of utilization of the parks. The data analysed from the respondents is an average of 2.38 which is between ‘almost never’ and ‘sometimes’ on the likert scale. The respondents indicate that they never (30.88%) and almost never (22.02%) utilize the parks. Thus, although respondents live or work near green areas, they never or almost never utilize these parks.

The purpose of question 2.5 was to determine the reasons for not utilizing the parks in order to determine if green rooftop systems might contribute to the solution.

The results regarding the reasons for not utilizing green areas in Johannesburg is presented in table 8.9. Column 1 lists various factors that may keep citizens from going to parks, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.9: Reasons for not utilizing parks

Factors driving Johannesburgers away from parks	**Average result**	**%**	**Ranking**
Crime	3.55	70.91%	1
Unsafe	3.53	70.61%	2
Lack of maintenance	3.02	60.30%	3
Filthy and littered	2.98	59.70%	4
Lack of privacy	2.83	56.67%	5

The main reason for not utilizing green areas is crime (70.91%). The second reason is unsafeness (70.61%), lack of maintenance (60.30%) is ranked third, filthy and littered (59.70%) is fourth and lack of privacy (56.67%) last.

The parks seem to be hot spots for crime and is generally unsafe; the two main factors that keep Johannesburg citizens away from green areas. The lack of maintenance also contributes to keeping people away from parks, but to a lesser degree than crime and unsafeness. Filthy and littered parks and lack of privacy is rarely the reason that keeps Johannesburg citizens away from green areas.

The respondents rate ‘secure and safe’ as an element to be a benefit to Johannesburg as13th (tabel 8.8) of importance of 14 elements, but crime and unsafeness as reasons for not utilizing Johannesburg parks as the highest. Therefore, Johannesburg may benefit from green roof systems in that regard.

Question 2.6 tests if Johannesburg is a sustainable city. The purpose of the question is to determine the sustainability of Johannesburg without green rooftop systems. The results received from the respondents is an average of 2.66 which is between ‘disagree’ and ‘neutral’ on the Likert scale.

From the views of the respondents, it may be concluded that Johannesburg is not a sustainable city. Therefore green rooftop systems may be a viable option in order to contribute to the sustainability of the city.

Health is another benefit provided by vegetated spaces. The purpose of question 2.7 was to determine to what degree green spaces contribute to the health of the respondents. Various health benefits were explored in order to determine to what degree vegetated spaces contributes to health. The results regarding the health benefits provided by vegetated spaces is given in table 8.10. Column 1 lists various health benefits, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.10: Health benefits from vegetated spaces

Health benefits from green spaces in cities as seen by Johannesburgers	Average result	%	Ranking
Promoting health	4.03	80.59%	1
Decreasing stress	4.01	80.29%	2
Reducing depression	3.62	72.35%	3
Reducing anxiety	3.60	72.06%	4
Improving worker productivity	3.50	70.00%	5
Reducing patient recovery time	3.29	65.88%	6

Promoting health (80.59%) is ranked first, decrease stress (80.29%) is ranked second, reducing depression (72.35%) third, reducing anxiety (72.06%) fourth, improving worker productivity (70.00%) fifth and reducing patient recovery time (65.88%) last.

The two health benefits from green areas are promotion of health and decreasing stress. Reducing depression, reducing anxiety, improving worker productivity and reducing patient recovery time seem to be benefits of green areas, but to a lesser degree.

Green areas seem to have various health benefits. The health benefits might encourage people to prioritize living or working within a close proximity of green areas.

The aim of question 2.8 was to determine if respondents would prioritize living and or working close to green areas due to the health benefits.

According to the data analysed, 77.94% of the respondents would prioritize living and or working close to green areas because of the health benefits that the green areas offer. Health seems to be an important factor to the respondents and most respondents (77.94%) would prioritize living and/or working within close proximity of green areas. Green areas are thus important to the respondents, although most of them did not want to utilize these areas due to crime and unsafeness.

Question 2.9 was asked to determine the rentability of residences with green rooftop systems in Johannesburg. The aim of the question was to determine if tenants would pay more for property with green roof systems. The respondents indicated that 76.47% would rather pay more in order to live in an apartment in a building with an exclusive green area and 23.53% would not pay more rent. The majority of respondents were willing to pay for exclusive green areas. The deduction, therefore is that there is a demand for green areas such as green rooftop systems and developments may still be feasible because tenants are willing to pay for it.

8.2.4 Section 3 Empirical Data

Section 3 consists of five questions regarding construction of green rooftop systems. The opinions of respondents were analysed using a Likert scale of 1 to 5 where 1 is strongly disagree and 5 is strongly agree. The opinions of the different professions and citizens were analysed separately but did not distort the data.

There are three purposes with the questions in section 3. Purpose one was to determine the knowledge and experience of the professionals in the construction industry regarding the construction of green rooftop systems. Purpose 2 was to determine what factors may hinder the development of green rooftop systems and the third purpose was to determine what ways would be effective to encourage the development of green rooftop systems in South Africa.

The purpose of question 3.1 was to determine how many of the respondents had experience with the construction of green rooftop systems. The results of the respondents were analysed to determine the experience of the respondents in the construction of green rooftop systems and are presented in table 8.11. Column 1 lists the various responding groups, column 2 presents the number of respondents that had experience with the construction of green rooftop systems, column 3 indicate the number of respondents that had no experience with the construction of green rooftop systems and column 4 is the total.

Table 8.11: Experience in constructing green rooftop systems

Experience in constructing green rooftop systems	Yes	No	Total
Citizens	0	40	40
Subtotal - None Proffessionals	0	40	40
Percentage of subtotal	0.00%	100.00%	100.00%
Quantity Surveyors	1	19	20
Architects	2	1	3
Engineers	0	3	3
Contractors	0	2	2
Subtotal - Proffesional team members in construction industry	3	25	28
Percentage of subtotal	10.71%	89.29%	100.00%
Total	3	65	68
Percentage of total	4.41%	95.59%	100%

According to the data analysed, as many as 95.59% of the respondents had no experience in the construction of green rooftop systems. The data clearly indicate that a lack of experience in the construction of green rooftop systems is a problem and that the professional members did not have experience, and therefore did not advise on construction of green rooftop systems.

The results regarding the factors to take into consideration when constructing a green rooftop system are illustrated in table 8.12. The purpose of question 3.2 was to determine what factors are important to take into consideration when aiming to construct a green rooftop system. Column 1 lists various factors to take into consideration with the construction of green rooftop systems, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.12: Factors to consider when constructing a green rooftop system

Factors to take into consideration when constructing a green rooftop system	Average result	%	Ranking
Drainage	4.44	88.82%	1
Weight loading	4.35	87.06%	2
Location and climate	4.24	84.71%	3
Water usage problems	4.22	84.41%	4
Access to the roof	4.09	81.76%	5
Availability of the materials	3.94	78.82%	6
Professional consultants	3.81	76.18%	7
Specializing suppliers	3.75	75.00%	8

The analyses of the response from the respondents is that drainage (88.82%) is the most important factor to take into consideration when constructing a green rooftop system. Secondly weight loading (87.06%), thirdly location and climate (84.71%), fourthly water usage problems (84.41%), fifthly access to the roof (81.76%), sixthly availability of the materials (78.82%), seventhly professional consultants (76.18%) and lastly specializing suppliers (75.00%).

The two factors that need to be taken into consideration when constructing a green rooftop system are drainage and weight loading. Both drainage and weight loading are elements that may cost money when it needs to be altered for green rooftop systems. It seems that the most important factors that need to be considered is the factors that will have a financial impact. Drainage, weight loading, location and climate, water usage problems, access to the roof, availability of the materials, professional consultants and specializing suppliers are, however, important factors to take into consideration as per the response from the respondents. The factors do not vary more than 13.82%, which may indicate that all the factors are important to the respondents.

South Africa has water shortage problems and gardens require water, different options need to be explored in order to solve the water shortage problem. The purpose of question 3.3 was to determine what options would be best preferred when taking water shortage into account.

The results regarding the different options to manage water shortage problems together with green rooftop systems are provided in table 8.13. Column 1 lists various options to work around water shortage problems, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.13: Options to consider when water is a problem in South Africa

Alternative options when faced with water shortage	Average result	%	Ranking
Gather storm water	4.37	87.35%	1
Recycle building water	4.25	85.00%	2
Choose vegetation indigenous to location and climate	4.01	80.29%	3
No green rooftops	2.04	40.88%	4

Gather stormwater (87.35%) is ranked first as an option to consider when water in South Africa is a problem, recycle building water (85.00%) is ranked second, choose vegetation indigenous to location and climate (80.29%) third and no green rooftop systems (40.88%) last.

Gathering of stormwater seems to be the respondents' first option in order to compensate for water shortage. Recycled water and indigenous vegetation, however, are also definite viable options to compensate for water shortage. The respondents indicated that no green roofs is not an option to solve water problems.

Green rooftop systems seem to come with disadvantages that might limit the development thereof. Question 3.4 lists some of these disadvantages. The data analysed regarding the factors limiting the development of green rooftop systems are given in table 8.14. Column 1 lists various limiting factors to the development of green rooftop systems, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.14: Factors limiting the development of green rooftop systems

Factors limiting the development of green roof systems	Average	%	Ranking
Structural integrity	4.10	82.06%	1
High cost	3.99	79.71%	2
Maintenance	3.46	69.12%	3
Vermin problem	3.31	66.18%	4

The data analysed indicated that structural integrity (82.06%) is ranked first, high cost (79.71%) second, maintenance (69.12%) third and vermin problem (66.18%) last.

Structural integrity seems to be the most important factor that may limit the development of green rooftop systems, as well as high cost. Maintenance and pest problems are ranked lower and are less important factors that may limit the development of green rooftop systems in contrast with structural integrity and high cost.

Green rooftop systems is a relative new concept in South Africa and the development thereof need to be encouraged. There seems to be various ways of encouraging the growth of certain developments. Question 3.5 state different methods to encourage the development of green rooftop systems in South Africa, specifically Johannesburg.

The results regarding the different ways to encourage the development of green rooftop systems in South Africa are presented in table 8.15. Column 1 lists ways to implement the development of green rooftop systems, column 2 presents the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.15: Encouraging the development of green rooftop systems in South Africa

Ways to implement green roof systems in South Africa	Average result	%	Ranking
Incentives	4.12	82.35%	1
Public buildings as displays	3.99	79.71%	2
Municipal grants	3.93	78.53%	3
Building regulations	3.84	76.76%	4
State legislation	3.69	73.80%	5
Competitions and awards	3.46	69.12%	6
Communication, negotiation and persuasion	3.21	64.12%	7

The data indicate that incentives (82.35%) is ranked first as a way to implement green rooftop systems in South Africa for development. Public buildings as displays (79.71%) is ranked second, municipal grants (78.53%) third, building regulation (76.76%) fourth, state legislation (73.80%) fifth, competitions and awards (69.12%) sixth and communication, negotiation and persuasion (64.12%) last as ways to implement green rooftop systems in South Africa for development.

Incentives seem to encourage the development of green rooftop systems the most in South Africa according to the respondents. Public buildings as displays, municipal grants, building regulations and state legislation seems to be grouped secondly as ways that would encourage the development of green rooftop systems in South Africa. Competitions and awards and communication, negotiation and persuasion seem to be less successful ways to encourage green rooftop systems in South Africa. Thus, incentives may be the most important way to develop green rooftop systems in South Africa, specifically Johannesburg.

8.2.5 Section 4 Empirical Data

Section 4 consists of two questions regarding vegetation to green rooftops in South Africa, but more specifically Johannesburg. The data of respondents were collected using a Likert scale of 1 to 5 where 1 is strongly disagree and 5 is strongly agree. The opinions of the different professions and citizens were analysed separately but did not distort the data.

The purpose of this section was to determine which of the list of indigenous plants are preferred by the respondents for green roofs in Johannesburg. Plants have different characteristics, therefore it seems necessary to determine the characteristics best suitable for rooftops in South Africa.

The data analysed regarding the different characteristics that seem to be the best suitable for rooftops in South Africa are illustrated in table 8.16. Column 1 lists preferred characteristics of plants, column 2 the average rating, column 3 reflects the percentage and column 4 the ranking.

Table 8.16: Preferred characteristics for rooftop plants

Preferred characteristics of plants on roofs	Average result	%	Ranking
Little maintenance required	4.39	87.76%	1
Aesthetic	4.33	86.57%	2
Draught resistant	4.13	82.69%	3
Heat resistant	4.13	82.69%	3
Indigenous	4.07	81.49%	4
Wind resistant	4.00	80.00%	5
Hardy	3.97	79.40%	6

The characteristic that seems to be the most important and ranked first is little maintenance required (87.76%), aesthetic (86.57%) is ranked second, drought resistant (82.69%) and heat resistant (82.69%) third, indigenous (81.49%) fourth, wind resistant (80.00%) fifth and hardy (79.40%) last.

Little maintenance seems to be the characteristic that respondents prefer most for plants to be on green rooftop systems. However, the characteristics aesthetic, resistant, heat resistant, indigenous, wind resistant and hardy are important to the respondents and may be preferred for green rooftop systems.

In question 4.2 indigenous plants that may be suitable for rooftop conditions in Johannesburg were presented to the respondents in order to determine which of the plants might be the best plants to use with green rooftop systems.

The analysed data regarding the different plants are given in table 8.17. Column 1 lists different plants, column 2 presents the average rating for the entire group, column 3 reflects the percentage and column 4 the ranking.

Table 8.17: Preferred plants for rooftops

Preferred plants for rooftops	Average result	%	Ranking
Kranz Aloe	3.75	75.00%	1
Soap Aloe	3.66	73.13%	2
Klipsalie	3.58	71.56%	3
Lemon thorn	3.48	69.69%	4
Pineapple lily	3.41	68.13%	5
Meelplakkie	3.39	67.81%	6
Porkbush	3.28	65.63%	7
Drooping agapanthus	3.25	65.00%	8
Doll's powderpuff	3.25	65.00%	8
Snake flower	3.17	63.44%	9
Slymstok	3.14	62.81%	10

The data analysed indicate that Kranz Aloe (75.00%) is ranked first, Soap Aloe (73.13%) second, Klipsalie (71.56%) third, Lemon thorn (69.69%) fourth, Pineapple lily (68.13%) fifth, Meelplakkie (67.81%) sixth, Porkbush (65.63%) seventh, Drooping agapanthus (65.00%) and Doll's powderpuff (65.00%) eighth, Snake flower (63.44%) ninth and Slymstok (62.81%) last as preferred plants.

The aloes, Kranz Aloe and Soap Aloe, and Klipsalie seems to be the most popular plants amongst the respondents to plant on green rooftop systems. Lemon thorn, Pineapple lily, Meelplakkie, Porkbush, Drooping agapanthus, Doll's powderpuff, Snake flower and Slymstok are less popular than the Aloes and Klipsalie, but are, however, still acceptable by the respondents to plant as rooftop plants.

8.3 CONCLUSION

The questionnaire was circulated to practising quantity surveyors, architects, engineers and contractors in the construction industry as well as citizens of Johannesburg by means of email. The response rate was 42.77%.

The respondents indicated that they were familiar with green rooftop systems, yet citizens seem to be more familiar with the concept of green rooftop systems than the professionals.

Green rooftop systems are not well known or seen in South Africa, as 57.35% of the respondents had never seen a green rooftop system in South Africa. Some of the respondents had seen green rooftop systems in Gauteng, Western Cape, KwaZulu Natal and Northern Cape.

Regarding the type of green rooftop systems, the respondents considered that the semi-intensive green rooftop system to be the most feasible for South African circumstances and intensive green rooftop system to be not feasible at all.

Improved air quality emerged as an important factor that may encourage the development of green rooftop systems. The second to fifth important factors are aesthetics, recreational space, habitats and job creation that may encourage the development of green rooftop systems.

It seems that Johannesburg may benefit the most from the improved air quality offered by green rooftop systems. The elements that stand out from which Johannesburg seems to benefit are improved air quality, better insulated buildings, job creation, aesthetics and eliminating the heat island effect.

Improved air quality, job creation and aesthetics are three elements that encourage the development of green rooftop systems as well as being beneficial to Johannesburg. Thus, the three elements may be regarded as the components that may encourage professionals and citizens to develop green rooftop systems in the Johannesburg area.

The data indicate that 73.53% of the respondents live and or work within 1km of a green area, although they do not make use of these areas due to reasons such as crime and general unsafeness. The respondents indicate that they do no utilize the green areas, but these areas may contribute to the promotion of health, decreasing stress, reducing depression, reducing anxiety and improving worker productivity. The majority of the respondents were however willing to pay more for property with a green rooftop system.

The respondents indicated that they did not have any experience in the construction of green rooftop systems, but that factors such as drainage and weight loading need to be taken into consideration when constructing a green rooftop system. Regarding the problem of water shortage, the respondents indicated that gathering of stormwater, recycled water and indigenous vegetation would rather be considered than not developing green rooftop systems.

Structural integrity seems to be the most important factor that may limit the development of green rooftop systems as well as high cost, but incentives may encourage the development.

The respondents indicated that the type of plants preferred for green rooftop systems are those that require little maintenance. Plants that are aesthetically pleasing, resistant, heat resistant, indigenous, wind resistant and hardy are important, to be successful on the rooftops of buildings. The preferred plants are the aloes, Kranz Aloe and Soap Aloe, and Klipsalie that seem to be the most popular plants according to the respondents.

In Chapter 9, the summary of the study, findings and conclusions, as well recommendations for further research are presented.

CHAPTER 9: CONCLUSION AND RECOMMENDATION

9.1 INTRODUCTION

The study consists of an introduction to study, a literature review, empirical section, findings and conclusions.

9.2 SUMMARY OF STUDY

The problem of the study is as follows: Rooftop gardens are not getting the recognition for their value to the environment, the citizens, the industry and the buildings as such in South Africa. This is due to lack of knowledge and innovation.

In Chapter 2 the history of green rooftop systems worldwide was reviewed. The anatomy of green rooftop systems were reviewed as well as the different types of green rooftop systems. The types of green rooftop systems are extensive, semi-intensive and intensive. A comprehensive comparison was done as this might contribute to the decision making as to what green rooftop system to install.

In Chapter 3, the possible effects of green rooftop systems to the surroundings and environment were reviewed. The advantages are insulation to a building, extension of roof membrane, sound insulation, slowing down the spread of fire, retain stormwater, mitigate the urban heat island effect, create habitats, food production, recreational space, increase air quality, increase property values, reduces stress, reduces patient recovery time, improves worker productivity. Building regulations may need to be amended to encourage the development of green rooftop systems.

In Chapter 4, the design and construction of a green rooftop system were reviewed. The factors to take into consideration when constructing a green rooftop system are the location and climate, weight loading, the professional team needed, drainage and access to the roof. The materials needed to construct a green rooftop system were reviewed as well as the availability of the materials in South Africa.

In Chapter 5, indigenous plant species were identified that may thrive on rooftops in South Africa and more specifically Johannesburg.

In Chapter 6, the research design and methodology were presented. The research data were collected by quantitative and qualitative methods. Field notes were taken as the qualitative method and questionnaires were sent out as the quantitative method to analyse data.

Chapter 7 presented the field notes of existing green rooftop systems in the Johannesburg area.

Chapter 8 presented the empirical findings to determine the South African perspective on green rooftop systems.

9.3 FINDINGS

9.3.1 First hypothesis

The first hypothesis of the study is as follows:

> *Green rooftop systems is a new concept in South Africa and underdeveloped.*

The hypothesis was shown to hold. The literature and empirical data confirmed that green rooftop systems is a new concept in South Africa and underdeveloped. The citizens among the respondents were familiar with the concept of green rooftop systems but the professionals among the respondents less so. Only a few respondents had seen a green rooftop system in South Africa. Green rooftop systems had, however, been seen in Gauteng, Western Cape, KwaZulu Natal and Northern Cape.

The respondents did not have experience regarding the construction of green rooftop systems, and thus indicated why professional members of the construction industry did not recommend the development thereof. This further indicates that there is a lack of knowledge in the industry regarding the construction of green rooftop systems and the benefits that accompany green rooftop systems. Despite the lack of knowledge in the industry, the materials needed to construct green rooftop systems are available in South Africa.

9.3.2 Second hypothesis

The second hypothesis of the study is as follows:

> *South Africa, and specifically Johannesburg, will benefit from the development of green rooftop systems, despite water shortage.*

The hypothesis was proven correct. Johannesburg seems to benefit most from improved air quality and better insulated buildings. Other benefits also include job creation, aesthetics, eliminating the heat island effect, stormwater management and economic growth. Respondents do not utilise existing green areas due to crime and unsafeness, and green rooftop systems provide a secure and safe green area. Green areas also provide health benefits such as promotion of health, reducing stress, depression and anxiety.

Despite water shortage, green rooftop systems may still be developed as the respondents would rather consider alternative options such as the gathering of storm water, recycled water of the building and indigenous vegetation accustomed to the climate because of the benefits provided by having green rooftop systems.

9.3.3 Third hypothesis

The third hypothesis of the study is:

> *There is a demand for green rooftop systems in South Africa and the developments thereof will be feasible.*

The hypothesis was shown to hold. The majority of the respondents indicated that they are willing to pay more rent for a property with a green rooftop system. They also indicated that it is a priority for them to live and or work in a close proximity of green areas due to the health benefits. Therefore there is a demand for green rooftop systems in Johannesburg.

Drainage and structural integrity are important factors that may limit the development of green rooftop systems due to the financial impact. Incentives seem to be the best way to encourage the development of green rooftop systems according to the respondents. Therefore, finance is a concern for the development of green rooftop systems in South Africa, however, there is a demand for it as the respondents are willing to pay more rent for property with green areas. Property value thus increases with the development of green rooftop systems and absorbs the financial impact thereof.

There are different types of green rooftop systems with different cost implications and according to the respondents the semi-intensive green rooftop system will be feasible for South African circumstances. The field notes presented that the few existing green rooftop systems in Johannesburg are semi-intensive green rooftop systems.

9.3.4 Fourth hypothesis

The fourth hypothesis of the study is as follows:

> *Green rooftop systems will conserve indigenous plant species.*

The hypothesis was proven correct. The literary review indicates that conditions on rooftops require plants to be hardy, drought resistant, heat resistant and wind resistant in order to be successful; the respondents agreed with this. The respondents also preferred plants for rooftops to require little maintenance, be aesthetically pleasing and indigenous. The literary review indicates that there are indigenous plants that may be successful on rooftops. The respondents indicated that they prefer Kranz Aloes, Soap Aloes and Klipsalie. Green rooftop systems may thus conserve indigenous plant species and create habitats.

9.4 CONCLUSION

Green rooftop systems represent a new concept in South Africa that is underdeveloped due to a lack of knowledge in the construction of green rooftop systems and a lack of knowledge regarding the benefits provided by green rooftop systems to the surroundings thereof.

Johannesburg will benefit from green rooftop systems. The citizens and environment will benefit from improved air quality, better insulated building, job creation, aesthetics, eliminating the heat island effect, stormwater management and economic growth, increased property values, sustainable city, secure and safe areas, promotion of health and decrease in stress, anxiety and depression as well as the conservation of indigenous plant species.

The financial impact of the development of green rooftop systems is a concern. However, there is a demand for green rooftop systems and therefore increases property value, thus developments are feasible regardless of the extra costs. Despite water shortage, respondents would rather use alternative methods to solve the water shortage problem than not to develop green rooftop systems.

To encourage the development of green rooftop systems in South Africa, and specifically Johannesburg, incentives may play a role. Improved air quality, job creation and aesthetics are three elements that will encourage the development of green rooftop systems as well as being beneficial to Johannesburg. Thus the three elements are regarded as the components that will encourage professionals and citizens to develop green rooftop systems in the Johannesburg area.

9.5 RECOMMENDATIONS FOR FUTURE RESEARCH

9.5.1 Recommendations for industry

The lack of experience and knowledge regarding the construction of green rooftop systems in the industry is a concern and should be addressed. This can be done in the form of seminars, courses and formal education.

There is a demand for semi-intensive green rooftop systems in South Africa and the benefits to the environment and city is significant, thus the develop thereof will be beneficial and should be encouraged.

Due to water shortage problems in South Africa, it is recommended to use only indigenous vegetation, therefore require further research for the construction industry as such.

Research regarding the building regulations and adjustments, in order to incorporate green rooftop systems in developments seems essential.

9.5.2 Recommendations for further research

Areas that require further research:

- The different options to solve water shortage problems (recycled water from building, gathered storm water and indigenous vegetation) can be researched in order to determine how much each will cost and the feasibility of the system.
- Further studies can be done in order to identify all the possible plants that have characteristics such as little maintenance, aesthetic, drought resistant, heat resistant, indigenous, wind resistant and hardy for roofs of the different cities in SA.
- Market research need to be done in order to determine the exact value a green rooftop system add to the value of a building, as well as the breakeven point.
- Research need to be done on the costs to change existing roofs to green rooftop systems in order to determine what the shortcomings are; is there any installation problems, leakage problems, drainage problems and/or vegetation problems.
- Study need to be done in order to determine the cost per square meter, in South African currency, for the different types of green rooftop systems for new and existing buildings.

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ANNEXURE A: QUESTIONNAIRE

UNIVERSITY OF THE FREE STATE

DEPARTMENT OF QUANTITY SURVEYING AND CONSTRUCTION MANAGEMENT

Dear respondent,

SURVEY ON GREEN ROOF GARDENS IN SOUTH AFRICA

As a professional, your assistance with this research project would be highly appreciated. The aim of the questionnaire is to obtain opinions on green rooftop gardens in South Africa. The research is conducted as part of a MSc in Quantity Surveying study.

Your participation through completion of the questionnaire will be highly appreciated and will contribute to the success of the research project.

The information you supply will be regarded as highly confidential and will only be used for purposes of this study.

My study leader, Dr. Benita Zulch, is assisting me. If you wish to contact her, you can reach her at 051 401 3849.

Thank you for your time in reading and completing the questionnaire within 2 weeks. Completed questionnaires should be emailed to rolien072@gmail.com.

GREEN ROOFTOP SYSTEMS: A SOUTH AFRICAN PERSPECTIVE

The intention is to determine the current status of green rooftop systems in South Africa, how knowledgeable construction team members are regarding the subject, the possibilities for green roofs in South Africa and the implementation thereof.

Please use X to mark the box that indicates your opinion regarding the level or answer most applicable to your environment.

Personal data:

Profession in construction industry:

Engineer	
Architect	
Quantity Surveyor	
Project Manager	
Contractor	
Other (specify)	

Citizen of Johannesburg Metropolitan:

Yes	
No	

SECTION 1: INTRODUCTION TO GREEN ROOFTOPS

1.1 Are you familiar with the concept of green roof gardens/systems?

Yes	
No	

1.2 Have you seen a green roof garden/system in South Africa?

Yes	
No	

1.3 If your answer is yes in question 1.2, in which province/s?

Gauteng	
Western Cape	
Kwa-Zulu Natal	
Free State	
Eastern Cape	
Northern Cape	
North West	
Limpopo	
Mpumalanga	

WHEN ANSWERING THIS QUESTIONNAIRE

Please indicate your opinion related to the level of importance in respect of the listed statements, circling the appropriate number in each row. Please answer all questions. The scale is as follows:

1 Not important
2 Fairly important
3 Important
4 Very important
5 Extremely important

1.4 Which type of green rooftop system would best be feasible for an average South African citizen?

A: Extensive	B: Semi-Intensive	C: Intensive
		
Vegetation: Sedums, moss, perennials. Low plant diversity. Low maintenance. Low initial cost. No recreational space.	Vegetation: Perennials, small shrubs, succulents, lawn. Medium plant diversity. Medium maintenance. Medium initial cost. Pleasant recreational space.	Vegetation: Shrubs, trees, lawn. High plant diversity. High maintenance. High initial cost. Excellent recreational space.

A: Extensive	1	2	3	4	5
B: Semi-Intensive	1	2	3	4	5
C: Intensive	1	2	3	4	5

SECTION 2: EFFECTS OF GREEN ROOFTOPS

2.1 Which factors will influence the development of a green rooftop building?

(1 = strongly disagree, 5 = strongly agree)

Green roofs provide insulation to a building that lessens the usage of energy.	1	2	3	4	5
Life extension of waterproofing on roof.	1	2	3	4	5
Sound insulation dampens the level of external noise.	1	2	3	4	5
Absorb and retain rainwater, thus limiting the rundown water and overflowing streets.	1	2	3	4	5
Minimizing heat island effect (more pleasant environmental air temperature).	1	2	3	4	5
Creating habitats & ecological biodiversity.	1	2	3	4	5
Creating recreational space.	1	2	3	4	5
Aesthetically pleasing.	1	2	3	4	5
Agriculture, cultivating food for the nation.	1	2	3	4	5
Improving air quality.	1	2	3	4	5
Secure and safe area.	1	2	3	4	5
Privacy.	1	2	3	4	5
Creating jobs in industry.	1	2	3	4	5
Demand from consumer.	1	2	3	4	5
Property value increases.	1	2	3	4	5
Identity	1	2	3	4	5
Memory	1	2	3	4	5
Belonging	1	2	3	4	5

2.2 Johannesburg will benefit from the following elements?

(1 = strongly disagree, 5 = strongly agree)

Well insulated buildings with a better temperature regulation, which leads to saving energy/electricity.	1	2	3	4	5
Life extension of waterproofing on roofs, thus less maintenance costs.	1	2	3	4	5
Sound insulation, which dampens the level of external noise.	1	2	3	4	5
Less overflowing of stormwater in the streets in heavy rainfall.	1	2	3	4	5
Minimizing heat island effect (more pleasant environmental air temperature, especially in summer maximum temperature is lower).	1	2	3	4	5
Creating habitats and ecological biodiversity.	1	2	3	4	5
Creating recreational space.	1	2	3	4	5
Aesthetically pleasing building environment.	1	2	3	4	5
Agriculture, cultivating food for the immediate community.	1	2	3	4	5
Improving air quality.	1	2	3	4	5
Secure and safe areas.	1	2	3	4	5
Privacy for individuals.	1	2	3	4	5
Job creation.	1	2	3	4	5
Economic growth.	1	2	3	4	5
Increased property values	1	2	3	4	5

2.3 Do you live or work within 1km of a green open park?

Yes	
No	

2.4 Mark on scale from 1 to 5 where 1 is never and 5 regular, the level of utilizing that open space/park?

(1 = never, 5 = regular)

1	2	3	4	5

2.5 Rate the reasons for not utilizing the open green spaces/parks.

(1 = strongly disagree, 5 = strongly agree)

Unsafe	1	2	3	4	5
Crime	1	2	3	4	5
Filthy and littered	1	2	3	4	5
Lack of maintenance	1	2	3	4	5
Lack of privacy	1	2	3	4	5

2.6 Is Johannesburg a healthy and sustainable city?

(1 = strongly disagree, 5 = strongly agree)

1	2	3	4	5

2.7 From a health perspective, do green spaces in the city contribute to?

(1 = strongly disagree, 5 = strongly agree)

Decrease in personal stress.	1	2	3	4	5
Improve worker productivity.	1	2	3	4	5
Reduce patient recovery time.	1	2	3	4	5
Reduce depression.	1	2	3	4	5
Reduce anxiety.	1	2	3	4	5
Promotes health.	1	2	3	4	5

2.8 Considering the health benefits as per question 2.7, would you make it a priority to work and live in close proximity to green spaces?

Yes	
No	

2.9 Which residence would you rather rent?

A: Apartment in a building with no exclusive recreational space to offer, for R7 000.00 per month.	B: Apartment in a building with exclusive green rooftop space to offer for R8 000.00 per month.

A	
B	

SECTION 3: CONSTRUCTING GREEN ROOFTOPS

3.1 Do you have any experience in the construction of a green rooftop system, either as part of your profession or personally?

Yes	
No	

3.2 Considering construction of green rooftop systems, rate the factors to take into consideration?

(1 = not applicable, 5 = extremely important)

Location and climate	1	2	3	4	5
Weight loading	1	2	3	4	5
Professional consultants	1	2	3	4	5
Drainage	1	2	3	4	5
Access to the roof	1	2	3	4	5
Availability of the materials	1	2	3	4	5
Specializing suppliers	1	2	3	4	5
Water usage problems	1	2	3	4	5

3.3 If water in South Africa is a problem, what will you do?

(1 = strongly disagree, 5 = strongly agree)

Ignore a green rooftop development.	1	2	3	4	5
Choose a green rooftop system that survives on the seasonal rain of the location. (Extensive system, see question 1.6)	1	2	3	4	5
Recycle water used by the building and re-use the water.	1	2	3	4	5
Gather storm water in a tank to be utilized for the green rooftop.	1	2	3	4	5

3.4 To what degree would the following concerns limit you from developing/encouraging a green rooftop system:

1 = not at all, 5 = completely)

Structural integrity	1	2	3	4	5
Maintenance	1	2	3	4	5
Vermin problem	1	2	3	4	5
High cost	1	2	3	4	5

3.5 How effective would the growth of green rooftops be in South Africa when implemented in the following ways?

(1 = strongly disagree, 5 = strongly agree)

Green rooftop systems are included in South Africa’s building regulations.	1	2	3	4	5
Communication, negotiation and persuasion of implementation (e.g. seminars).	1	2	3	4	5
Competitions and awards.	1	2	3	4	5
Public buildings as ‘displays’ of potential green rooftop buildings (e.g. schools, hospitals).	1	2	3	4	5
Municipal grants	1	2	3	4	5
State legislation	1	2	3	4	5
Incentives	1	2	3	4	5

SECTION 4: VEGETATION TO GREEN ROOFTOPS IN JOHANNESBURG

4.1 What characteristics in the plants would you prefer in the green rooftop system?

(1 = strongly disagree, 5 = strongly agree)

Hardy	1	2	3	4	5
Require little maintenance	1	2	3	4	5
Aesthetically pleasing	1	2	3	4	5
Draught resistant	1	2	3	4	5
Heat resistant	1	2	3	4	5
Wind resistant	1	2	3	4	5
Indigenous	1	2	3	4	5

4.2 Indicate the plants that are suitable for rooftop conditions, that you would consider planting on green rooftops?

(1 = strongly disagree, 5 = strongly agree)

Lemon Thorn		1	2	3	4	5	Drooping agapanthus		1	2	3	4	5
Pineapple Flower		1	2	3	4	5	Slymstok		1	2	3	4	5
Porkbush		1	2	3	4	5	Snake flower		1	2	3	4	5
Soap Aloe		1	2	3	4	5	Meelplakkie		1	2	3	4	5
Kranz Aloe		1	2	3	4	5	Doll's powderpuff		1	2	3	4	5
Klipsalie		1	2	3	4	5							

Thank you very much. Your valuable time is most appreciated.