THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES OF ÇANKAYA UNIVERSITY

DEPARTMENT OF INTERIOR ARCHITECTURE

ANALYSIS OF VEGETATED BUILDING ELEMENTS TO ACHIEVE ENERGY EFFICIENCY AND IMPROVE INDOOR AIR QUALITY IN BUILDINGS

MONDER M. HUSSAIEN AL MUDER

JULY 2017

ANALYSIS OF VEGETATED BUILDING ELEMENTS TO ACHIEVE ENERGY EFFICIENCY AND IMPROVE INDOOR AIR QUALITY IN BUILDINGS

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ABSTRACT

ANALYSIS OF VEGETATED BUILDING ELEMENTS TO ACHIEVE ENERGY EFFICIENCY AND IMPROVE INDOOR AIR QUALITY IN BUILDINGS

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Due to the increasing global demand for energy and the application of non-environment friendly building techniques, there is an ever-growing attention to environmental issues. Although many essential benefits of plants, such as absorbing chemical pollutants in air and regulating temperature are well-known, unfortunately they are still not efficiently integrated in building design. This thesis aims to increase the level of awareness regarding the benefits of vegetated building elements and hence, help to increase their application rates in order to achieve sustainable architecture practices by improving energy efficiency and indoor air quality. As to fulfilling these objectives, firstly an in-depth literature review, to provide a comprehensive guide that identifies the types, benefits, and techniques regarding the application of vegetated building elements was done. Moreover, a questionnaire which targeted academicians and professionals related to the field of architecture and construction in several countries was conducted. With this study, the importance of integrating plants in building elements was emphasized and the motivators and challenges for their applications were determined. It was seen that overall, there is reasonable knowledge of the application process, however, there is still the need to increase the level of awareness regarding the benefits of vegetated building elements, throughout communities. The application of vegetated building elements could significantly increase in future developments, if they were supported and adopted by governmental authorities and decision-makers.

Keywords: Sustainable Architecture, Vegetated Building Elements, Green Roofs, Green Walls, Interior Gardens, Indoor Air Quality, Energy Efficiency.

ÖZ

YAPILARDA ENERJİ VERİMLİLİĞİ VE İÇ MEKAN HAVA KALİTESİNİ ARTIRMA BAĞLAMINDA BİTKİLENDİRİLMİŞ YAPI ELEMANLARININ ANALİZİ

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Temmuz 2017, 116 sayfa

Küresel ölçekte artan enerji talebi ve çevre dostu olmayan yapı tekniklerinin kullanılması sebebiyle, çevresel konular her gün daha fazla dikkat çekmektedirler. Her ne kadar bitkilerin havadaki kirleticileri filtreleme ve sıcaklıkları dengeleme gibi faydaları biliniyor olsa da, maalesef halen bina tasarımına yeterince etkin bir şekilde entegre edilememektedirler. Bu tez çalışması, bitkilendirilmiş yapı elemanlarının faydaları konusundaki farkındalık seviyesinin artırılmasını ve bu sayede uygulama oranlarını artırarak, enerji verimliliği sağlamak ve iç mekan hava kalitesini iyileştirmek bağlamında sürdürülebilir mimari uygulamalarını mümkün kılmayı hedeflemektedir. Bu amaçlar doğrultusunda öncelikle, bitkilendirilmiş yapı elemanları tiplerinin, yararlarının ve tekniklerinin tanımlandığı kapsamlı bir kılavuz oluşturmak adına derinlemesine bir literatür taraması yapılmıştır. Bunun sonrasında, mimarlık ve inşaat alanında yetkin, birkaç ülkede akademik platformda ve sahada çalışan profesyonellere yönlendirilmiş bir anket uygulaması yapılmıştır. Bu tez çalışması ile, bitkilerin yapı elemanlarına entegrasyonunun önemi vurgulanmış, ve uygulamalarına

ilişkin teşvik edici ve engel teşkil eden faktörler belirlenmiştir. Çalışma sonucunda yapılan genel bir değerlendirme ile, söz konusu uygulamaların sürecine ilişkin yeterli seviyede bilgi sahibi olunduğu ancak, bitkilendirilmiş yapı elemanlarının faydaları konusundaki farkındalık seviyesinin artırılması gerektiği görülmüştür. Bitkilendirilmiş yapı elemanları, hükümet makamları ve inşaat sektöründeki karar merciileri tarafından desteklendikleri takdirde, gelecek faaliyetlerde bunları içeren uygulamaların büyük oranda artması mümkün olacaktır.

Anahtar Kelimeler: Sürdürülebilir Mimarlık, Bitkilendirilmiş Yapı Elemanları, Yeşil Çatılar, Yeşil Duvarlar, İç Bahçeler, İç Mekan Hava Kalitesi, Enerji Verimliliği.

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LIST OF ABBREVIATIONS

HVAC	Heating, Ventilation and Air Conditioning
IAQ	Indoor Air Quality
UHI	Urban Heat Island
PVC	Polyvinyl Chloride
VOCs	Volatile Organic Compounds
CO	Carbon Oxide
CO_2	Carbon Dioxide
NOx	Nitrogen Oxide
SRI	Surface Reflectance Index
NO	Nitric Oxide
LCA	Life Cycle Assessment
HC	Hydrocarbon
ACH	Air Changes Per Hour
ITCZ	Inter-tropical Convergence Zone
ET	Evapotranspiration
HIRI	Heat Island Reduction Initiative
SPSS	Statistical Program for Social Sciences

CHAPTER 1

INTRODUCTION

Nature have been serving humanity since his first emergence on earth, fulfilling many crucial needs such as, food, shelter fuel and a collection of other goods. Furthermore, vegetation is significantly important for humans as plants eliminate carbon oxide (CO), carbon dioxide (CO_2) and other harmful gases found in the atmosphere, by their process of photosynthesis, producing oxygen, while minimizing global warming and their effect on climatic changes. With the technological advancements, urbanization, excessive use of energy, and industrial and economic developments, the production and consumption of materials have increased. Hence, the emission of gases and chemicals in the atmosphere have increased, which created a catastrophic global pollution problem. The negative impacts of pollution on the quality of life became a challenge in urban communities. Thus, using sustainable design criteria became an essential factor in both buildings and urban systems. Architects, planners, and urban designers are once again seeking for a solution to the current environmental and social problems in 'green infrastructure', that requires the consideration of a whole host of interconnected elements. Based on the idea of implementing green roofs, walls and the internal gardens, designers are trying to provide multiple environment-friendly systems in buildings and urban areas. Among these functions; reducing air pollution, providing energy savings, reducing high temperatures, and mitigating urban heat island effect to provide ideal living conditions can be found.

Merging 'the living systems' such as; green walls, roofs and internal gardens, with the inorganic and lifeless structures that currently dominate buildings, a product of the collaborative work of landscape designers, architects, and agricultural engineers, is promising a new type of architecture, by positively affecting the exterior shell and interior of the building, alongside its surrounding environment. Undoubtedly, pollution outside the buildings affects indoor air quality in buildings, especially with the use of natural ventilation, which lead to the transmission of outside pollutants into the buildings. If mechanical air ventilation systems were used in buildings, this is a common cause of spreading the pollutants and diseases between interior spaces in buildings. Thus, the relation between indoor and outdoor air quality is strong. As it is the case for energy consumption of buildings, exterior temperature extremely affects the interior temperature inside buildings, which requires consuming more power in an attempt of cooling. Hence, using indoor plants such as interior green walls and gardens in buildings represents the current fast solution for processing indoor air quality "two plants per 100 sq ft or two plants per a small office keep the air pure and healthy" (Wolverton, Johnson & Bounds, 1989, p. 9). Whereas using plants in green roofs and exterior green walls reduce energy consumption in buildings due to plants characteristics. Eliminating outdoor air pollution and urban heat island effect in urban cities, represent sustainability and ensure healthy cities and buildings in the future. As the Environmental Protecting Agency (EPA) declared "green roofs provide shade and remove heat from the air through evapotranspiration, reducing temperatures of the roof surface and the surrounding air" (EPA, 2016, p. 1).

As a result of the contribution of the community as a whole in preserving the natural environmental elements and emphasizing the importance of sustainable construction methods, which can make the natural landscape a home to many of the world's population, the prosperity of our planet will be ensured.

1.1. Aim and Scope

The research attempts to clarify the priorities of the community and the government regarding green development and to reduce the extent of the environmental effects of buildings on their surroundings and their users. This can be achieved by providing environment-friendly buildings that have lower energy (or zero energy) consumptions and help to reduce the pollution caused by human activities. The research focuses on the utilization of vegetated elements at roofs, walls and interior spaces in buildings, and providing data related to the mentioned issue for all the stages of a building (design - construction and installation - post-installation). Moreover, in order to support the application of vegetated building elements, the motivators and barriers acting upon the users, owners, and decision makers in the public and private building sectors were tried to be found out. Important design considerations and suitable systems to provide less impact on the environment and improve user health due to the integration of plants in the building fabric were tried to be reached. The aim of this study was to increase the level of awareness regarding the benefits of vegetated building elements and to find out the extent of the possibilities and challenges of their applications. By this way, increasing the rates of the application of vegetated building elements to achieve energy efficiency and improve indoor air quality in buildings could be possible for future developments.

1.2. Methodology

Firstly, an extensive literature survey related to the topic has been done. The definition of the concept of sustainable architecture, its role in improving the quality of life, as well as reducing energy consumption in buildings were given. The sources of pollution and types of air pollutants through building materials and human activities were pointed out. Moreover, the types, characteristics and design standards for different systems of green roofs, walls and interior gardens were studied. The differences between systems in terms of used materials, installation methods, maintenance, irrigation requirements, cost, etc. were examined by giving reference to example buildings containing these systems. Furthermore, the benefits of integrating plants in buildings and the improvements for the users and the community as a whole were identified. The impacts of the types and characteristics of various plants on air pollutants, in both short and long terms were investigated. The possible barriers regarding different climatic conditions and their effects on the success of application were studied. Moreover, the role of governments and organizations in the application of vegetated building elements were also studied by mentioning the incentives, rewards and policies provided recently in several countries. Regarding the analysis of the level of awareness and the possibility of applying vegetated building elements, as well as investigating the motivators and barriers of the application of vegetated building elements, a questionnaire was conducted online via Google Forms, which is a specialized website for creating questionnaires and surveys. It was distributed to different countries (Turkey, Libya, Canada, and Malaysia) with different climatic zones evenly as 15 copies to each climatic zone. Furthermore, it targeted academicians and professionals in the fields of architecture, civil engineering, urban design, urban design, planning, agronomy, and investors. A copy has been sent to each participant as an email in English language. In total 60 responses from four climatic zones.

1.3. Structure of the Thesis

This thesis contains six chapters. All the important information about the application of green roofs, walls, and interior gardens to achieve energy efficiency and improve indoor air quality in buildings, the used methods and their analysis can be found for different climatic zones. The first chapter of this thesis includes an introduction, aim and scope, as well as methodology of this thesis. Whereas the second chapter includes an introduction of sustainable architecture and air quality in buildings as well as global effect of pollutants. The third chapter examines the vegetated building elements including, systems types, differences, design considerations, installation and characteristics. Furthermore, the fourth chapter investigates the possibilities and challenges of the application of vegetated building elements, including climatic conditions, choosing the correct plants, the policies and incentives. Moreover, the fifth chapter includes questionnaire for professionals and academics in the field of construction regarding the level of awareness and the possibility of application. Finally, the sixth chapter includes the conclusion and recommendations.

CHAPTER 2

SUSTAINABLE DEVELOPMENT

Sustainable development attempts at finding a solution for the increasing problems in the world, and it is interested in the quality of life and seeks innovation and development at the same time with maintaining the environment system and natural resources (Smit & Pilifosova, 2003). The most common definition of sustainable development is by the World Commission of Environment and Development (WCED): “addressing the needs of the present without underlining the needs of the future” (Brundtland, 1987, p. 16). It is seeking to analyze and process the world issues in a clearer approach by classifying them into three sectors in a parallel way: Environmental, Economic, and Social (Emas, 2015). Sources and methods of construction are affecting on achieving sustainability. As The Organization for Economic Co-operation and Development (OECD) mentioned that the field of construction contributes significantly to the sustainable development (Fankhauser, 2013). For that reason, it is known as the keystone of sustainability. Cities are filled with environmental, economic, and social problems (Dempsey, Bramley, Power & Brown, 2011). Thus, creating urban cities, healthy environments, and communities aware of the importance of sustainability in future development would ensure a better life for future generations (Moon, 2007).

2.1. Sustainable Architecture

Sustainable buildings provide benefits to communities as they incorporate certain design approaches and use technologies to ensure the health and well-being of their occupants. Providing high air quality through innovations, technologies and regulatory amendments in an attempt to reduce the negative effects on the atmosphere, the ozone layer and climate change, caused by human activities like the use of heating, ventilation and air conditioning systems (HVAC), as well as fuel and electricity, is a primary concern of many professionals from the fields of architecture, engineering, environmental management, medicine and finance, which would improve the quality of life and the environment (Ray, 2000). Merging sustainable elements, and materials can help to achieve progress in architecture, which significantly contribute to the promotion of the concept of eco-friendly construction and the creation of civilized cities that pay attention to health, recreation and welfare by means of conservation of biological diversity and the natural characteristics. Decision for sustainable application of technology to lessen the environmental impact of buildings should be integrated in the early stages of design, as it is difficult and costly to implement them in the later stages. Moreover, having conscious communities that have an awareness of the impacts of building on their occupants is essential. On the other hand, the life cycle of a sustainable building should be considered as 'cradle-to-cradle', instead of 'cradle-to-grave', by reducing the environmental impact of the building through the processes of recycling, reusing and not becoming waste. Therefore, sustainable architecture is concerned with all the life stages of a building and struggles to provide suitable environments and a better life for future generations (Kim & Rigdon, 1998).

2.2. Environmental Quality

Many of the air quality issues are associated with the levels and sources of pollution that release some molecules, compounds and toxic chemical gases into the atmosphere. Those molecules are not present in the atmosphere composition or they are present but in a smaller percentage. This chemical composition interacts with the natural atmosphere, and that in turn affects the ecosystem which supports life. Pollution factors can be physical (radiation), or mechanic (stuck particles), or chemical (chemical substance). All these pollutants are a cumulative result of various sources but humans are the main responsible agent. Since the beginning of the industrial revolution, with the increasing urbanization rates and population, the world has become increasingly dependent on fossil fuels to meet the needs of modern life, which leaves harmful gases such as, nitrogen oxide (NO_x), volatile organic compounds (VOCs), CO, CO_2, etc (Daly & Zannetti, 2007). All of these pollutants are released into the air as a result of the daily activities of man, which causes serious damage to the ecological balance and threaten life on earth. Especially the wind has an important role in transferring the local and regional pollutants. The gases that cause global warming and acid rain can cause severe damage to humans and animals whether it is short-term or long-term (Gheorghe & Ion, 2011). In addition to the anthropogenic human involved emissions, it is also important to consider the non-biological emissions, such as the gases emitted from volcanoes and forest fires due to lightning and high temperatures. It may also be an important factor regarding pollution and its negative effects on climatic changes. Therefore, if air would be defined as something that is completely clean, then unfortunately in this era it may be hard to find air anywhere on earth (Daly & Zannetti, 2007). The pollution cycle on a global scale can be seen in Figure 2.1.

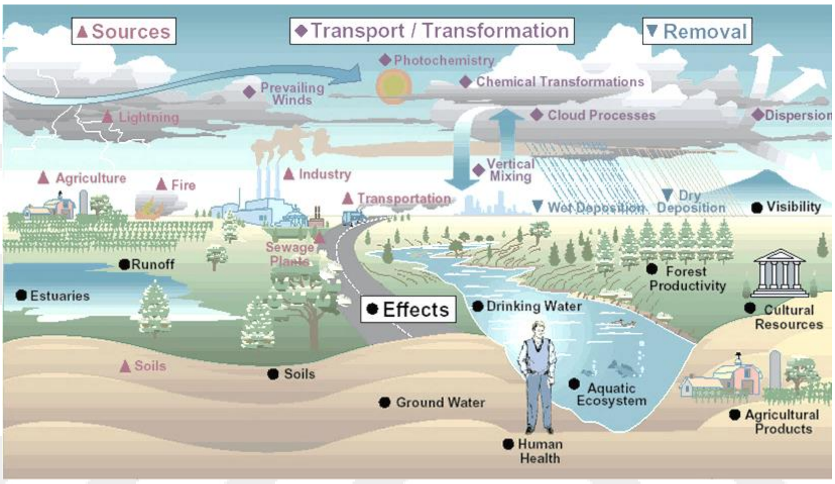

Figure 2.1. *Global Pollutants Cycle,* (Gheorghe & Ion, 2011)

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2.2.1. Global Effect of Pollutants

Air pollution results from human activities and natural sources, which certainly have negative effects globally. Pollutants can be classified as primary and secondary. Primary contaminants are emitted directly from the source to the atmosphere, such as; Carbon compounds (CO - CO_2 - CH_4 - VOCs), Nitrogen (NO - N_2O - NH), Sulfur (H_2S - SO_2), Halogen (chlorides and fluorides), and Particulate Matter (PM) (Daly & Zannetti, 2007). While the secondary contaminants are not emitted directly from the source, but they are produced through the interaction of primary pollutants in the atmosphere, both the primary and the secondary contaminants cause severe harm to the environment. Examples of Secondary contaminants are NO_2 and HNO_3 formed from NO and Ozone (O_3) formed from nitrogen VOCs and oxides, Sulfuric and nitric acid droplets are formed from NO_2 and SO_2, ammonium nitrate and organic aerosols, as illustrated in table 2.1 (Gheorghe & Ion, 2011).

Table 2.1. *Pollution Types and Their Impacts on Health, and Environment* (Gheorghe & Ion, 2011).

	Pollutant	Origin	Effects
Natural sources of pollution	Sulphur, chlorine, and ash. Particulates, smoke and carbon monoxide methane volatile organic compounds (VOCs), due of burn and deforestation: CO_2, NO_2, CO, N_2O, NO, NH_4.	Wildfires. Volcanoes. Pine trees. Cattle and other animals.	- Smog. - Acid rain. - Increased respiratory. - Damage cell. - Respiratory irritant. - Diseases membranes of plants the effects are high only for volcanoes.
Anthropogenic sources of pollution	Carbon monoxide, nitrogen oxides, sulphur dioxide, carbon dioxide. Fluorides and substances with fluorine, bromine (Br_2) and iodine (I_2), chlorine (C_{12}), VOC, small dust particles, methane, ammonia and radioactive radiation.	- Industry: the mining industry – the energy industry based on fossil oil and natural gas extraction – fuels – coal – oil. - Central heating, chemical and metallurgical industry. - The production of hydrofluoric acid, phosphate chemicals and fertilizers. - Engineering internal combustion machinery industry, industrial waste, noises.	- Respiratory irritant. - Increased respiratory. - Formation of secondary pollutants. - Effect on soil fertilizer. - Acid rain. - Respiratory diseases. - Greenhouse gas effect. - Carcinogenic properties. - Toxic effects - Stratospheric ozone deletion. - Accumulation in tissues. - Blocking of different processes.
	CO, CO_2, NO, NO_2, NH_3, CH_4, SO_2, oxides of heavy metals, H_2SO_4, SPM, HC, VOC, background dust: sulphur oxidation of salt sea that including gases, same organics, nitrous oxide (N_2O) pesticides.	Agriculture: the vegetation fire, the denitrification process, in soils excessively fertilized and the pesticides, deforestation.	- Stratospheric ozone depletion. - Formation of secondary pollutants. - Respiratory diseases. - Greenhouse gas effect. - Acid rain. - Toxic effects.

All of these chemical pollutants do not stay in one place, but the movement of air and weather conditions play an important role in transferring the contaminants and spreading them all over the world. As shown in Figure 2.2, the pollutants react with the atmospheric compounds and turn out to be aggressive and toxic products which can affect human health directly or indirectly, also leading to the depletion of the ozone layer and global warming.

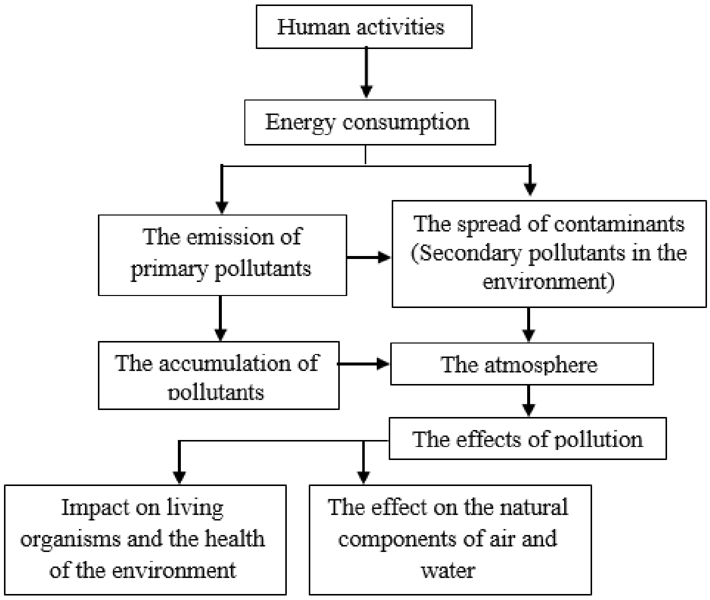

Figure 2.2. *The Flow of Air Pollutants* (Produced by the Author).

2.2.2. Indoor Air Pollution

Buildings where people spend most of their time in, become crucial spaces to control air pollution. As a result, if the air quality inside buildings was ignored, there could be a massive disaster, it could have disastrous effects on human health, as pollutants can accumulate and reach a concentration more than that of outside. Not only the contaminants entering the buildings, but also some daily human activities inside buildings can increase this issue such as, smoking, using stoves, heaters, air conditioners, as well as using building materials that release NO, CO, SO_2, VOCs (Daly & Zannetti, 2007). If the traditional solution of good ventilation through windows and openings is depended upon, the problem of indoor air quality could overlap with the outdoor air quality problem, as both would suffer from the spreading of contaminants. Perhaps one of the best strategies for eliminating toxic chemical compounds in indoors could be benefiting from natural tools such as, using vegetated elements and integrating interior gardens in buildings.

Table 2.2. *Potential Pollutants Caused by Building Materials* (Lee, Biasio & Santini, 1996).

	Building Material	Possible Pollutants
Wood Product	Plywood Particle board Medium density fiber board Chipboard & oriented strand board	Urea- and phenol – formaldehyde
Insulation	Foamed in place Rigid board Batt	Particulate: formaldehyde, resins, hydrocarbons, polyurethane, polystyrene. VOC: Urea– formaldehyde; benzene, Benz-aldehyde, asbestos, acetaldehyde. Cresol: methyl naphthalene, anomia, acrolein, phenol.
Paints	Solvent-based Carpeting Water-based Concrete	Aromatic hydrocarbons, aliphatic hydrocarbons. VOC. Biocidal additives, butylene, acrylics, styrene, vinyl. Formaldehyde: VOC; synthetics fibers; nylon; latex rubber; polypropylene.

CHAPTER 3

VEGETATED ELEMENTS IN SUSTAINABLE ARCHITECTURE

According to the United Nations, more than 50% of world's population live in urban areas, which becomes more populated every year, and it is expected to increase to more than 66% in 2050 as a result of immigration to urban cities (United Nations, 2014). This increase has negatively affected the environment and health. Thus, architecture seeks for the implementation of sustainable approaches to address these issues by replacing building elements that are used from glass, concrete, metals, and high albedo materials with vegetated coverage. The conventional building materials reflect the solar radiation back and increase temperatures 10°C more, which increases the need for energy as to cooling the environment (Ottelé, Perini, Fraaij, Haas, & Raiteri, 2011). The reflection of surfaces is measured using Surface Reflectance Index (SRI). The increase in its value means the increase in the reflection of the material, and that in turn affects the reflection of solar radiation. Thus, sustainable architecture is seeking to find more effective solutions by using environment-friendly techniques and building systems through increasing green spaces, including vegetated building elements of walls and roofs, due to the plants' ability to absorb and lower solar radiation levels. (Victorero et al., 2015).

Cities have massive surface areas as to roofs and walls of buildings, which usually are left untreated, and a major part of them could be used to contribute as a supporting agent for environment (Franco, Fernández, Pérez, & Valera, 2012). As the pioneer of bio-climatic architecture, Ken Yeang has said:

> We need to start building our cities out of soft and natural, as opposed to the hard and largely unnatural. Not only would this be a huge stride forward in addressing the environmental challenges of the period, but it would also create a new, exciting aesthetic that reflects the environmental age we live in (Wood, Bahrami, & Safarik, 2014, p. 11).

3.1. Green Wall Systems

Green walls refer to all form of plants grown in a vertical manner, which could be installed to both interior and exterior walls or in some cases it could be self-supported, that is either entirely or partly covered with plants, soil and growing medium (Timur & Karaca, 2013). Landscape designers, and specialists refer to it as living walls, bio-walls or vertical gardens, which is an element of vegetated architecture (IMAP, 2014). These terms are used to describe the vegetation of vertical species of diverse plants (Timur& Karaca, 2013).

The concept of green walls in history goes back to 600 to 800 B.C, when Babylonians built one of the worlds’ seven wonders, which is known as the hanging gardens of Babylon. The aim was to benefit from plants in order to protect the building from wind, as well as to shade it. Also, it was used to take advantage of the vertical surfaces as to the limited horizontal spaces to plant agricultural crops (Sharp, Sable, Bertram, Mohan, & Peck, 2008). This strategy was continued to be used for a long time in countries with hot climate. In the medieval eras, plants were trained to climb on the walls of castles and palaces (Wood et al., 2014). In the eleventh century, Vikings used a kind of brick that was made from build-up of plants that are incompletely decayed (peat’s bricks) which is created from swamps or similar environment and used as part of housing elements. The use of this brick allows the grass to grow naturally on the walls, so the building was covered by grass, and their roots helped the bricks to merge with each other to make the wall stronger. These structures could be found wherever the Vikings lived, but there is no evidence that this green wall was made on purpose (Aupetit & Lundberg, 2011). The first time the term ‘Green Wall’ or ‘Vertical Garden’, was used, was in 1988 by the French botanist Patrick Blanc, who owns the patent for his vertical garden which is known as the: “mur végétal”. Since then, the use of green walls has spread worldwide and the application techniques have been developed further (Wood et al., 2014).

Over the centuries, the green wall technique has been applied usually in the form of plants being attached to the external walls. However, the vegetated wall system has been recently evolved to include the internal elements of the building structure, by providing prefabricated elements and vertically homogeneous soil, or a hydroponic system in order to grow plants on a vertical surface. These systems of planting vegetation require differing structures to keep the plants' positions and ensure their continuous growth, as they involve biological diversity and depend on the characteristics of the plants. Thus, the process of creating green walls usually requires considering a wide range of plants that could be used, and the interior lighting conditions (IMAP, 2014). Moreover, the design process requires sufficient knowledge on considerations regarding the maintenance and irrigation. As any other techniques in its inception has faced challenges in how to continue to a longer time period (Green-screen, 2012).

3.1.1. Types of Green Walls

Green wall types are diverse. In general they can be divided into two categories: green facades and living walls, which could further be branched into other classifications, as shown in Figure 3.1.

Green facades are usually created through supporting structure or hanged plants which hide their roots in the soil, and grow in a vertical direction, upward or downward (Elgizawy, 2016). Living walls provide dense and diverse species of plants, such as ferns, and perennial flowers. Thus, they require more attention. They are made of panels or plastic models with three parts: a PVC layer, a metal frame, and the medium of growth. Moreover, they can be applied successfully in several climates. Commonly automatic watering and nutrition systems are used to ease the maintenance process of the living walls (Sharp et al., 2008). All categories of the green walls achieve the same purpose, but the difference lies in the ability of growth, survival and maintenance (Elgizawy, 2016).

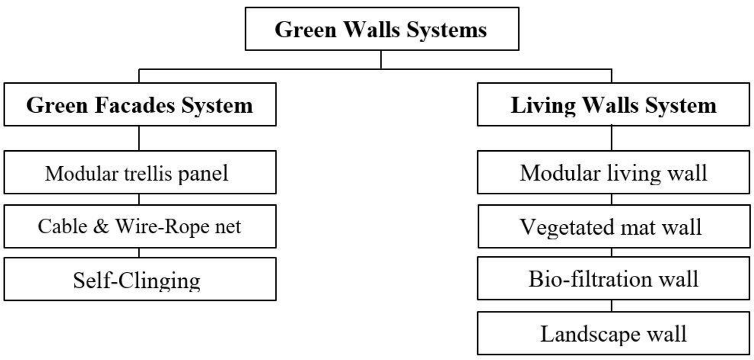

Figure 3.1. *Classification* of *Green Walls* (Produced by the Author).

3.1.1.1. Modular Trellis Panel System

This system is inspired by the green roof system which uses rigid and lightweight modules as a supporting medium, and offer a three dimensional design, with its horizontal, vertical, and structural depth that is needed for supporting plant growth and flexible expanding (Othman & Sahidin, 2016). The system consists of powder coated galvanized and welded steel wire that might be recycled. The panel itself is also recyclable. The trellis panel keeps a distance from the wall, through a series of horizontal supports, so that the plants do not attach to the building's membrane, and protect its integrity. The panel size in some custom designs depend on the facade and the needs, but generally the sizes are standardized as 4:6, width to length ratio (Elgizawy, 2016). The system promotes self-standing walls and curved structures by accumulating and gathering the panels to expand all around the facade, as seen in Figure 3.2 (Timur & Karaca, 2013). The irrigation in this system takes advantage of the gravity to distribute water from the top to the bottom by installing the irrigation system on top of the modular system (Othman & Sahidin, 2016).

Figure 3.2. *Installation Process of Modular Trellis Panel System* (Timur & Karaca, 2013).

3.1.1.2. Cable & Wire-Rope Net System

These systems use either cables or wires. Cables are designed to facilitate the climbing of plants for faster growing and denser foliage on green facades (Elgizawy, 2016). Wire-nets are mostly designed to facilitate plants with slower growing rates that need an additional support, as to nearby intersections, as seen in Figure 3.3. They provide a wider selection design applications as they are more flexible (Sharp et al., 2008).

Figure 3.3. *Cable & Wire-Rope Net System Displaying Intersected Clamps* (Sharp et al., 2008).

3.1.1.3. Self-Clinging System

In this system, plants that have the ability for self-clinging are used, such as Boston Ivy, English Ivy and Virginia Creeper. These plants hide their roots in the soil and grow vertically to cover wall surface completely. Watering the plants is accomplished in a natural way, vertically with rain or against the gravity, by pulling the water from the soil by the roots and then distributing it to the leaves (Sharp et al., 2008). The plants of Boston Ivy and Virginia Creeper typically do not cause damage to the surfaces, but English Ivy, on the other hand, supports itself via its hanged roots along the surface that damage the structure by causing cracks when penetrating, as seen in Figure 3.4. Thus, it creates difficulties at the time of removing the plants or maintenance (RHS Advisory Service, 2016).

Figure 3.4. *The Climbing of the Ivy and Virginia Creeper, Respectively* (Sharp et al., 2008).

3.1.1.4. Modular Living Wall System

Recently, this system has appeared partially in the green roof applications, together alongside with the advancements in sustainable architecture. It includes growing media inside a square or rectangular panels that consists of overlapping parts of lightweight materials such as plastic, polypropylene or metal sheet. They may also come in different shapes, like planter tiles, or trays (Elgizawy, 2016). The configuration of the growing medium could be customized depending on the selected plants. The modular system is usually pre-grown, which offers immediate green after finishing the installation, as seen in Figure 3.5 (Timur & Karaca, 2013). Irrigation in this system is provided at various heights along the wall, where water moves through the growing media by taking advantage of gravity (Sharp et al., 2008).

Figure 3.5. *The Installation of Modular Living Wall That Has Been Grown Before* (Timur & Karaca, 2013).

3.1.1.5. Vegetated Mat Wall System

It is a distinctive system of green wall established by the French designer Patrick Blanc, and it consists of two layers of synthetic fabric with pockets which facilitate the growing media and plants, as seen in Figure 3.6. There is a frame that provides support for the fabric wall, backed by a water proof membrane as to high humidity (Elgizawy, 2016). The irrigation system cycles the water from top to bottom, and distributes the nutrients along the system (Sharp et al., 2008).

Figure 3.6. *The Installation of Vegetated Mat Wall System* (Timur & Karaca, 2013).

3.1.1.6. Biofiltration Wall System

This type of green walls consist of a hydroponic system, which contains dense roots and microbes between two layers of fabric, which allows air circulation through it. This air infiltration through the plants can lessen the concentration of VOCs, as the leaves take in CO_2 and CO, as seen in Figure 3.7 (Sharp et al., 2008). This process produces fresh air, which is distributed into the indoor spaces by means of a fan. One of studies of the University of Guelph has shown that, this system can reduce indoor air pollutants up to 30% through this biological process (Darlington & Arsenault, 2012).

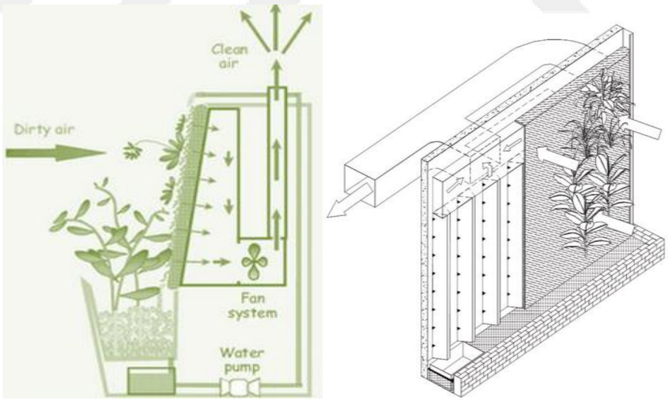

Figure 3.7. *The Biofiltration Wall System and Its Process* (Sharp et al., 2008).

3.1.1.7. Landscape Wall

This type has emerged as a result of the landscape development in architecture, in order to make buildings approach nature. The walls in this system are sloped, rather than vertical. They have functions such as reducing noise and stabilizing sloped landscapes surrounding the building. They are made up of concrete and plastic, providing spaces for plants and the growing medium to be stacked on top of each other, as seen in Figure 3.8 (Timur & Karaca, 2013).

Figure 3.8. *The Stages of Installing the Landscape Wall System* (GEOsystems, 2014).

3.1.2. Green Wall Design Considerations

There are various factors that should be taken into consideration when starting to design a project with green walls, as these factors highly affect the ability of application. Hence, the designer must make an appropriate choise depending on the characteristics of the site and the type of building (Green-screen, 2012). By using a checklist to ensure the safety of the building, the project can be successful. Design considerations for green walls that should be taken into account are as follows:

1. Site considerations

The characteristics of the site can be an advantage or disadvantage due to the feasibility and cost. Therefore analyzing the site is an important factor to determine its suitability, in terms of: sun rotation, availability of water, amount of soil, the level of nutrients in soil, and the local climate, as illustrated in Table 3.1. These characteristics affect the correct plant selection, because plants react differenty under various conditions (Green-screen, 2016).

Table 3.1. *The Site Considerations and Climatic Factors for Green Walls* (Green-screen, 2016).

Wind	Average wind speeds are greater at height than at ground level. Winds may be strong around the edges of buildings, or from the down draft caused by tall buildings. It will be necessary to understand the likely wind load that a green wall will be subjected to, so that it can be built to withstand the forces.
Rainfall and Irrigation	Rainfall will not generally be sufficient to support a green wall throughout the year. It is important to establish whether rainwater or another water source can be harvested from other areas on site, and stored to supply an irrigation system. This will avoid or minimise the need to use potable water for irrigation.
	Selection of plants with less water need or suitable plants for local micro-climate, so that only precipitation would be sufficient and no extra irrigation after one year.
Solar Radiation	Light intensity also tends to be greater at height than at ground level. At height there are fewer structures, no vegetation to absorb solar radiation and increased reflection from adjacent buildings and surfaces. Conversely, there some buildings that may receive significantly less solar radiation, due to intense shading by nearby buildings. Shading analysis can be used to assess areas of light and shade on a site and possible changes over the year (e.g. equinox).
Air Temperature	Temperatures in urban environments tend to increase with elevation, due to the increased thermal mass of built structures and the commensurate heat gain. Assessing the likely temperature range on a site is crucial in planting design, particularly in extreme temperature events.

2. Soil volume considerations

The characteristics of soil is a critical factor for the success of green walls. Over the years, the volume and components of the soil have been studied to ensure the growth of plants (Green-screen, 2016). James Urban, an employee of FASLA, which is one of the specified organizations in this area, stated in that his studies the relation of plant to the volume of soil, needs to be as; a clipper of 40.5 cm to 28 m^3 of soil volume (Urban, 2008). Green walls have been examined for over a decade and it has been concluded that, plants can extend to dimensions of 15 cm to 20 cm when provided limitless soil, delivering the maximum spread and height of the plants (Green-screen, 2016).

3. Irrigation considerations

It is important to know the appropriate irrigation system for green walls regarding the requirements of plants. Several green wall systems require high levels of water. Thus, it is recommended to find alternative solutions such as using non-potable water. The need for irrigation could be estimated based on a number of characteristics, such as: the ability of storing water, evaporating, effective rainfall, plants' properties, and seasonal changes (IMAP, 2014). Irrigation techniques vary based on the plant types, such as plants with vains, or container plants, but in general the roots are the basic vessel in the irrigation process (Green-screen, 2016).

4. Life-cycle Expectations

The expectations for keeping green wall system in a good state for long time depend on the building's conditions. The expected lifecycle for the system also depends on the design intention. Some projects remain for decades, while others are modified frequently for more modern solution, and therefore being designed and constructed according to new concepts (Green-screen, 2016). "The building life span is assumed to be 50 years" (Altan, John, & Yoshimi, 2015, p. 994). On the other hand, the average life span of different green wall systems reaches up to 18 years (Altan et al., 2015). Manufacturers which have finished a Life Cycle Assessment (LCA) are using 30 years as a reference point for the life span of the product. Moreover, plants could live for hundreds of years assuming for perfect conditions (Green-screen, 2016). Thus, an extended life span should be aimed, and incorporating several disciplines in the design process should be taken into consideration; that involves the user, various designers, and the producer (Green-screen, 2016). Table 3.2. illustrates a number of components used in the green wall systems and their life span expectations.

Table 3.2. *Several Components of the Green Walls and Their Life Cycle Expectations* (Brajkovic, 2014).

Components	Material	Service Life (Years)
Inner Masonry	Clay Brick (100 mm)	50
Thermal insulation	Mineral wool (70 mm)	50
Outer Mansory	Lime stone (50 mm)	50
Exterior finishes	Plaster- Gypsum	50
Inner layer	PVC foam plate (10mm)	10
Supporting system for vegetation	Polyamide Felt (3+3 mm)	10
Growing material	Goe-textil Brick	50
Irrigation system	PE pipes and flexible tube	7
Water demand	Tapwater + nutrients	1
Vegetation	Selected plants	10

5. Environmental Considerations

Characteristics of plants and the surrounding environment have an important role in the green coverage. Climate affects the nutrients needed in the soil, such as salts, water, etc. The increase or decrease in these fundamental ingredients in different environments may cause damage to the plants or the soil. For example, cold and coastal countries have high amount of salt, either stored in the soil or coming from snow. This excessive salt leads to the increase of soil PH, and the reduction of water infiltration and soil ventilation. Hence, soil compaction and water runoff occurs, and the photosynthesis process gets interfered (Green-screen, 2016). Plants play a vital role in water runoff as well as other important environmental issues. Therefore, when green walls are incorporated in a certain building, attention should be given to the strategies that are suitable to the local environment.

6. Engineering requirements

Since the architectural techniques differ according to the varying building structure, special attention should be given to requirements for attaching walls, the type and form of system appropriate for application, and installation methods. Designing spaces for installing these systems should be done by specialists with an approach that ensure ideal coverage for the entire wall, without blocking natural lighting and ventilation for indoor spaces. Furthermore, loads from green wall applications differ based on the used materials, which usually require metal frames. These loads require examination and calculations of structural engineers to make sure to provide the appropriate load bearing systems in the building (Sharp et al., 2008).

7. Maintenance considerations

Green wall systems require frequent maintenance, hence, the amount of maintenance to be performed by the user is a fundamental factor to determine the type of system and plants to be applied (Sharp et al., 2008). The clearance between the wall and the backside of the installed plants is a significant parameter. The systems that are 15 cm or closer to the wall need a certain type of plant that twists so that it will not touch the wall. Furthermore, walls that are higher than 2.5 meters would require a ladder for maintenance, and it is recommended to have a minimum of 46 cm space between the wall and the plants to allow a proper care for the plants and air flow (Green-screen, 2016).

The location and climatic conditions affect the amount of irrigation and the possibility of water access to the soil in order to neutralize it. Maintaining irrigation systems, which play a fundamental role in keeping the plants in a lasting flourish. In addition to that, some materials used in the application of green walls require continuous monitoring, and sometimes their replacement. For instance, wire-rope system requires frequent examination of the cable's tension to ensure the climbing of plants in a proper way during their growth (Sharp et al., 2008). Table 3.3 demonstrates some common maintenance tasks.

Table 3.3. *Green Walls Maintenance Goals and the Required Action* (IMAP, 2014).

Maintenance Objective	Task
Maintain planting design	Plant replacement, infill plantings
Maintain plant growth	Remove waste plant material , inspect for signs of pests, make seasonal adjustments to irrigation volume and frequency as needed, ensure adequate nutrition levels for plants; inspect after severe weather events (e.g. wind or heat) to look for signs of stress
Maintain climbing plants	Annual or biannual pruning to maintain density and cover and to remove growth from fixtures (windows, drains). Rejuvenate to renovate habit and growth. Vigorous pruning to renew stems and encourage new basal growth (every 5-7 years)
Maintain irrigation (and fertigation) systems	Manually test and inspect the irrigation system regularly and monitor any automated systems (check volume of irrigation delivered, its frequency, substrate moisture content, and, for hydroponic green walls)
Monitor plant nutrition	Maintain a log of fertiliser additions and records of pH and electrical conductivity values before and after addition of fertiliser
Maintain safety systems	Check safety anchor points for fall arrest systems, check access points, e.g. ladders and stairways, check electrical safety of power points, lighting and irrigation control system

8. Lighting considerations

Different plants need different amount of lighting to achieve proper growth and photosynthesis. Green walls are frequently installed in indoor spaces, where there is low levels of daylight. Hence, it is important to take the intensity and quantity of lighting into consideration by using natural light or a stable artificial light. The lowest amount of lighting for most indoor green wall plants is approximately 13000 to 26000 lux daily (Sharp et al., 2008).

9. Concept considerations

The conceptual approach for the application determines the system to be selected. As to requirements of a green wall project in a certain building, covering the surface completely or partially is an important factor that would affect the decision for the ideal system to be selected among the different systems of green walls (Green-screen, 2016). The important points for the application of green walls depending on the concept considerations are as follows:

Table 3.4. *The Considerations of Green Façade and Design Goals* (IMAP, 2014).

Design goals	Considerations
Low cost and easy to install	Use a direct attaching species of plant, grown from the ground at the base of the wall.
A multi-storey facade greening	Include containers at different heights, include cabling or lattice support structures for twining plants, ensure access for maintenance, provide irrigation, consider secondary protection of plants against stem damage.
Screening of an unsightly view	Use evergreen species to ensure year-round screening, create a structure for the plants to grow on.
Maximise thermal benefits	Use deciduous species if heat gain is desired in winter; ensure very leafy plants, covering the entire wall for providing best shade in summer; provide a structure at least 100 mm off the wall for the plants to grow on, leaving an air gap between the building and green plants to maximise cooling effect.
Produce food	Increase depth and organic content of the substrate, ensure good access to the site, and provide irrigation.
Provide biodiversity outcomes	Include a variety of species, with habitat features such as nectar producing flowers, fruits, capacity to support nests, create protected or visually prominent areas.

Table 3.5. *The Considerations of Living Wall and Design Goals* (IMAP, 2014).

Design goals	Considerations
A multi-story green wall	Ensure access for maintenance, consider hydroponic system if weight loading is likely to be a problem, ensure species selection is appropriate for the light and wind exposures at different heights.
Aesthetics and a design statement on a building	Include a variety of species with different flowering times, consider planting in patterns, textures, foliage colors and extending the planting area beyond the boundaries of the green wall.
Low cost and easy to install on a residential building	Consider DIY installations, minimize the size of the system, self-contained units that recirculate water, systems that can be easily replanted.
Provide biodiversity outcomes	Include a variety of species with habitat features such as fruits or nectar producing flowers, or a niche design that provides protection from predators for particular species.
Internal green wall	Ensure adequate light – possibly install artificial light.
Long lasting wall	Consider quality of design and longevity of components.

1.1.3. Green Wall Installation and Characteristics

Green wall systems include any method for installing vegetation on walls. Conventionally, this system contained only climber plants. After the developments in architecture, these systems varied in the installation, used materials, characteristics, and the supporting systems to avoid possible problems, fit to the building method and goals, as shown in Table 3.6 and Table 3.7.

Table 3.6. *Classification of Green Facade Systems: Installation, Method, Used Materials, Characteristics and examples* (Produced by the Author).

		Modular trellis panel system	**Cable & Wire-Rope net**	**Self-Clinging system**
Installation method		It offers horizontal, vertical and depth. The trellis panel keeps a distance from the wall through series of horizontal supporters. The system promotes self-standing walls and curved structures by accumulating and gathering the panels to expand.	The cables are connected in a grid using cross clamps. Hand-installed terminal end fittings allowed field trimming of ropes and rods for simplified installation. System attachment and tensioning allows easy install/detach.	Plants that are capable of climbing are rooted at the base of these structures, in the ground, in intermediate planters or even on rooftops. Thus, the plant grows and climbs to cover the facade by their root structure.
Materials		Powder coated galvanized, welded steel wire, plants, steel edge trim, clips, irrigation system.	Tensioned stainless steel vertical wire ropes, horizontal wire rods, plants, irrigation system.	Rough surface, Climber plants, irrigation system.
Characteristics	**Coverage**			
	Extensive	-	✓	✓
	Intensive	✓	-	-
	Application			
	Outdoor	✓	✓	✓
	Indoor	-	-	-
	Assembly			
	Onsite	✓	✓	✓
	Offsite	-	-	-
Example		 The marketplace - Oviedo Crossing	 Pritzker family children's zoo	 Prussian state library - Berlin

Table 3.7. *Classification of Living Wall Systems: Installation, Method, Used Materials, Characteristics and examples* (Produced by the Author).

		Modular living wall	Vegetated mat wall	Biofiltration wall	Landscape wall
Installation method		It includes growing media inside a square or rectangular panels that consists of overlapping parts of lightweight materials, it comes with different shapes, such as planter tiles, tray.	This system is integrated with the building. Roots are hidden in the growing medium, which is in the pockets.	It consists of hydroponic system. Growing medium exists between two layers of fabrics, connected to ventilation system and a fan distribute fresh air after being treated by plants.	This system is installed on sloped walls through stacking material made of plastic or concrete with room for growing media and plants.
Materials		Panel that can be plastic, polypropylene or metal sheet. Plants, growing medium, frame, irrigation system.	two layers of synthetic fabric with pockets, waterproof membrane, Irrigation system.	Fan, pipes, frame, ventilation system, water pump, two layers of fabric, growing medium, vegetation, irrigation system.	Plastic or concrete modules, irrigation system plants, planter boxes
Characteristics	**Coverage**				
	Extensive	-	-	-	-
	Intensive	✓	✓	✓	✓
	Application				
	Outdoor	✓	-	-	✓
	Indoor	-	✓	✓	-
	Assembly				
	Onsite	-	✓	✓	✓
	Offsite	✓	-	-	-
Example		 Atlanta Botanical Gardens	 Antalya airport roadside	 Guelph Humber University	 Lampoon, Thailand

3.2. Green Roof Systems

Green roofs are also referred to as; roof gardens, living roofs, vegetated roof covers, and landscaped roofs. These systems include a vegetated layer that lays on the top of building structure supported with a growth media (Hui, 2011). National Roofing Contractors Association (NRCA) has described green roof systems as an area where different plants and trees are implanted and isolated from the ground by a minimum of one floor building structure (Engleback et al., 2003).

Eventhough ‘green roof’ is a modern term, these systems have been used for many years. They have been used on roofs to provide aesthetics such as Babylon’s hanging gardens, as well as to be effective as an isolators, as in the Scandinavian roofs (Clark, 2008). There are many building examples in the middle ages which have applied green roofs such as Mont Saint Michel in North of France in the 13th century, and Palazzo Piccolomini in Italy, which was built in the 15th century. Moreover, settlers in America have built houses completely from vegetation in the 19th century (Engleback et al., 2003). The use of green roofs had spread in between the years 1960 and 1970, in Switzerland and in Germany. However, they were facing challenges like leakage and loads, which in turn caused the establishment of a study group of the German Landscape Research, Development and Construction Society (FLL) in 1977, to support these systems as part of the environment and ecology in urban communities (Clark, 2008). The evolution of sustainable architecture in the recent years promoted the application of vegetated roof covers, to take advantage of their multiple benefits on the climate and environment, besides the advantage of their attractive designs (IMAP, 2014). However, the challenge is in their development to be cost-effective for residential, and commercial buildings.

3.2.1. Types of Green Roofs

Green roofs have been classified into three different categories: intensive, semi intensive, and extensive. The essential distinction between them is the used vegetation, construction method, and substrate depth (Carroll, 2010). Green roof systems are applied on a steel or concrete roof construction with different components and layers that provide insulation and protection. In addition, these systems are applied on an existing or new roof, as horizontal or sloped, depending on the architectural intention (DDC, 2007).

3.2.1.1. Intensive Green Roof System

Intensive green roof is basically a roof garden designed for the use of people offering the same amenities of a garden or park on ground level (Clark, 2008). Wide variety of plants could be grown, from grass to trees, based on the substrate depth. Thus, they should have a dense layer of soil, high level of water retention, and continuous irrigation. The substrate depth is from 150 to 1000 mm (Carroll, 2010). Moreover, intensive green roofs contain additional loads such as chairs, and pergolas, which create loads that need essential reinforcement of the current roof or incorporate a supportive building structure. They should also to be inspected during design and construction phases. Furthermore, these systems could not be applied in slopes of more than 3% as they are more appropriate for flat roofs. The used components, types of materials, and amenities for users determine the frequency of maintenance and cost (Lennep & Finn, 2008). Figure 3.9 shows an example of intensive green roof system in Chicago City Hall in USA.

Figure 3.9. *Intensive Green Roof* (Sowden, 2010).

3.2.1.2. Semi-Intensive Green Roof System

This type of green roof is hybrid, which contains a wide variety of vegetation that require frequent maintenance and irrigation (DDC, 2007). Using this type for incorporating amenities is mostly limited. Furthermore, in semi-intensive roof, less loads are enforced, which makes it a lighter and cost effective technique than the intensive green roof (Lennep & Finn, 2008). It is distinguished by its growing medium of 12 to 24 cm that consists of mineral-based organic soil and smaller plants, causing a weight load of 171 to 293 kilogram per square meter (DDC, 2007). As to the design of this system, visual diversity is generally overlooked, however, it may be occasionally achieved (Clark, 2008). Figure 3.10 shows an example of semi intensive green roofs in French embassy in Washington.

Figure 3.10. *Semi-Intensive Green Roof* (Furbish, 2015).

3.2.1.3. Extensive Green Roof System

This system of green roofs include evenly planted low vegetation, with a thin substrate layer from 40 to 200 millimeters (Carroll, 2010). This leads to a low weight system and minimal requirements for the building structure. The growing medium may contain recycled materials that composed minerals with a depth of 5 to 15 cm (Lennep & Finn, 2008). It can be applied to flat and sloped roofs up to 40% (Engleback et al., 2003). The maintenance is limited to the irrigation for the first year through plant implementing process and the infrequent weeding for the next few years, for invasive plant types (DDC, 2007). The commonly used plants are local, and the system is designed to be self-sustaining, and requiring no irrigation systems (Engleback et al., 2003). This system is usually not designed for recreational intent and accessibility, even though it offers an attractive view and an ecological function (DDC, 2007). Figure 3.11 shows an example of extensive green roof in Congresium building in Ankara, Turkey.

Figure 3.11. *Extensive Green Roof, Congresium Ankara, Turkey* (Photograph taken by author).

3.2.2. Green Roof Design Considerations

The application of green roofs requires studying the important considerations in the stages of planning and designing, to avoid possible problems and to benefit from offered advantages extensively. Following are the basic considerations for green roofs:

1. Site considerations

To achieve effective implementation and continuous greenery, it is important to understand the characteristics of the site, such as: the exposure to sun and wind, level of air pollution, the change in temperature, humidity levels, etc. The culture and microclimate on the directly roof affect the plant growth (Hui, 2011). Table 3.8 illustrates the main site and climate considerations for green roofs. Native plants are the most appropriate plants to use as they require less care and maintenance (Sharp et al., 2008). The height of nearby buildings is important as they can break wind and storm, and create shadow by blocking sun rays. Therefore, several micro climate factors are effective on green roofs (Hui, 2011).

Table 3.8. *Green Roofs Site Factors and the Collected Data* (FLL, 2008).

Site factors	Information to be Collected
Climate and weather	▪ Regional climate ▪ Local microclimate ▪ Expected rainfall volume and distribution throughout the year ▪ Average exposure to sunshine ▪ Shadowing effect of the surrounding buildings ▪ Any incidence of periods of drought ▪ Direction of prevailing wind ▪ Airborne contamination ▪ Expected maximum and minimum temperatures ▪ Whether it is located extremely close to sea or high on the mountain ▪ The wind which depends on the local wind zone, height of the building, roof type, slope, and area (whether corner, middle or edge).
Local environment	▪ Assess any opportunities or risks that nearby vegetation will have on the site - weed or pest invasion, biodiversity migration

2. Irrigation considerations

Green roofs face insolation and wind more than the ground surface. Design consideration for irrigation systems are related to factors such as: climate, environment and plant species, as well as the substrate characteristics regarding its ability to retain water. If not properly designed according to these factors, the system may result in water loss. Water resources in green roof systems are usually separated from groundwater. Hence, for limiting the consumption of fresh water, sources such as rainwater or waste water should be considered (Clark, 2008). The frequency of irrigation depends these mentioned factors. However, these systems generally need watering approximately twice or three times a week. It is important to organize the frequency of watering by considering the drainage, level of evaporation evaporating and the ability of water retaining. In addition, watering in high temperatures should be avoided as it causes direct transfer of heat to the building during its passage through the substrate (IMAP, 2014). There are many irrigation options as illustrated in Table 3.9.

Table 3.9. *Irrigation Methods* for *Green Roofs* (IMAP, 2014).

Method	Advantages	Disadvantages
Micro spray	Low cost, visible, easy to install, reliable	Uneven distribution (plant interception), high water loss (wind, evaporation), foliage wetting (increased disease potential)
Surface drippers/perforated pipes	Low cost, visible; more even distribution	Moderate water loss
Sub-surface drippers/perforated pipes	Low cost, moderate efficiency (water distribution to root zone)	Non visible (maintenance), higher potential for damage
Sub-surface capillary	High efficiency	Higher cost, maintenance and repair, ‘capillary rise’ of substrate needed
Wicking associated with irrigation in drainage layer	High efficiency, ease of installation	Could be unsuitable for plant establishment if the water is applied too deep for the plant roots to reach
Hose	Easy, plant monitoring	Higher cost (labour), low efficiency, foliage wetting, uneven distribution

Irrigation systems could by controlled be computers or be automatic. In the second case, rain sensors should be integrated to stop the irrigation system during rainfall. However, in automatic systems a person should be present to frequently observe the process (IMAP, 2014).

3. Protection layer considerations

- Protection mat: This type of protection layer is used to ensure the safety of waterproofing and root barrier. It is installed straight after the waterproofing layer if the membrane is root resistant, or above the root barrier layer. In addition, it could help to improve water retention and to absorb noise. Furthermore, water-permeable materials such as dense fibre could be used (Engleback et al., 2003).

- Root barrier layer: It is an important layer for green roofs, as it protects the waterproofing layer from penetration and damage. This layer is a separate layer made from ‘Polyethylene’ and it is installed above waterproofing to provide protection from plants roots (Lennep & Finn, 2008). Occasionally, the root barrier layer is integrated with the waterproofing layer and merged as a one layer, by using materials such as biocide, made from copper that is resistant to penetration, and bitumen waterproofing (IMAP, 2014). It is extremely important to ensure the capability of the used materials to resist the acids that result from the decomposition of plants (Lennep & Finn, 2008).
- Filter sheet: It is a thin layer installed directly under the growth medium, which allows the plant roots to pass through it. Furthermore, it helps to prevent the blockage of the drainage layer by filtering the impurities in the growing medium (IMAP, 2014).

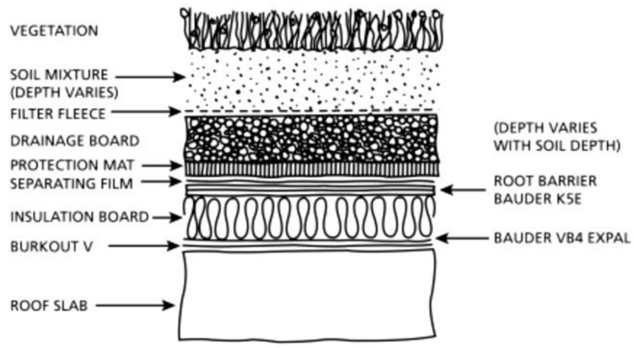

Figure 3.12. *Typical Green Roof Layers* (Engleback et al., 2003).

4. Water proofing

One of the most important elements of a green roof is water proofing, which can be also called a membrane (Engleback et al., 2003). The proper water proofing layer ensures the safety of the roof and reduces the need for maintenance. Hence, it is necessary to check if there is any leakage in the water proofing layer before installing the green roof, as it would be hard to repair it after application (Hui, 2011). It is recommended to have a continuous separation between the layer of plants and the membrane, or using a membrane that contains a root deterring chemical or metal foil, to ensure the safety of the membrane against root penetration (Engleback et al., 2003). Moreover, an appropriate drainage system should be used to help eliminate the extra water resulting from heavy rain and to prevent water moving from the wet environment to the building structure. When using different kinds of materials in water proofing, a special consideration must be given to their weight and the ability of the structure to withstand those loads (Hui, 2011).

5. Drainage considerations

It is necessary to have a drainage system in green roofs to avoid the accumulation of extra (unwanted) water. This system is designed according to the expectation of intensity and duration of rainfall in the site (Hui, 2011). There are two types of drainage systems. The primary system is usually put at the lowest point on the roof and consists of small holes installed on the green roof to gather the water until a certain level, so that it starts a positive drainage, as shown in Figure 3.13. The second type is an auxiliary system, which is installed at a higher height than the first system. This system is effective in case a blockage happens to the first system as a result of continuous heavy rain or the failure of closing the irrigation system (IMAP, 2014). Roofs that are partially installed with greenery must be designed with a suitable drainage system that includes both the vegetated and non-vegetated part of the roof, with taking into consideration to putting inspection chambers over drains (Hui, 2011). Moreover, a slight degree of slope helps the water to move to the specified places. Consequently, a higher slope means faster drainage (EAD, 2006).

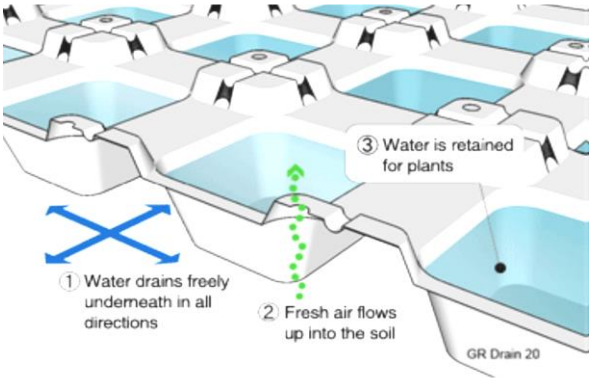

Figure 3.13. *Water Retaining and Drainage Process in Green Roof Systems* (Hui, 2011).

6. Weight loading

The expected loads must be studied in the design stage before implementing the green system on roofs. Moreover, determining whether the green roof is to be implemented on a new building or an existing roof is modified to be a green roof is important. Calculating the load ability of the building and the roof type (concrete, metal, wood) ensures a safe green roof that achieves the design intent (Engleback et al., 2003). The loads in green roofs vary and could be broadly divided into two types: Dead Loads; which cover the medium of growth, membranes, and paths, and Live Loads; which include people, winds, and rain loads (Hui, 2011). Plants and trees produce heavier weight during the succeeding years, therefore all these loads should be taken into consideration to maintain the safety of the building and to provide the proper building structure (Miklós, 1998). Table 3.10 shows several material loads of green roof.

Table 3.10. *Material Loads That Are Included in a Green Roof* (Hui, 2011; IMAP, 2014).

Building materials		**Substrate**		**Vegetation**	
Components	**Weight unit**	**Components**	**Weight unit**	**Components**	**Weight unit**
Stone (sandstone, limestone)	2300-3000	Gravel	16-19	Low herbaceous	10.2
Concrete (precast)	2100	Pebbles	19	low shrubs up to 1.5 m	10.2-20.4
Concrete (reinforced)	2400	Brick (solid with mortar)	18	Shrubs up to 3 m	30.6
Concrete (lightweight)	1300 - 1600	Sand	18-22	Small trees up to 6 m	40.8
Hardwood timber	730	Sand and gravel mixed	18	Medium trees up to 10 m	61.2
Softwood timber	570	Topsoil	17-20	Large trees up to 15 m	150
Cast iron	7300	Water	10		
Steel	8000	Gravel	16-19	-	-

7. Sloped roofs considerations

The installation and planting process of the sloped roofs is done on site. The stability and retaining of the growing medium must be ensured in this type, especially in sites exposed to strong winds, so that it does not lead to sliding as a result of the shear force (IMAP, 2014). Moreover, the calculation should be made and the appropriate planting method depending on the slope should be defined. Proper management of roof layers and locations of plants ensure soil stability and prevent erosion (Hui, 2011). Roofs with slopes of up to 15% may not need extra protection like sloped roofs of more than 15%, which require additional support for the growing medium to resist shear force (FLL, 2008).

8. Safety and fire prevention

There is no a certain fire risk linked with the green roofs. In fact, some of the green roofs are designed to provide fire resistance. However, certain criteria and techniques must be considered to ensure the prevention of those risks (FLL, 1995). "There is evidence suggesting that green roofs can help slowing the spread of fire to and from the building through the roof" (Hui, 2011, p. 42). When designing the green roofs, a gravel break of 1 meter should be regularly put every 40 meters (FLL, 1995). Also, the growing medium should be 30 millimetres or higher in depth, with organic matter not more than 20%, and a vegetation free zone or fire slabs of gravel or concrete must be installed every 40 meters, surrounding every penetration on the roof (Hui, 2011). Furthermore, plants that are highly flammable, or that are excessively thirsty should be avoided (EAD, 2006).

9. Maintenance considerations

Performing maintenance is highly important to achieve healthy growth for the plants, appropriate functioning of the roof layers, and the removal of unwanted vegetation (DDC, 2007). The maintenance depends on the roof type and the surrounding environmental factors. However, green roofs are usually designed for low maintenance. It is important to focus on maintenance in the first and second year of installation to achieve the intent of the design. Subsequently, a periodic maintenance is done to the structure of the building and the green roof system to ensure the safety of the building (IMAP, 2014). Occasionally, an emergency maintenance is needed if a certain component fails, such as a damage in the irrigation pipes or a blockage in the drainage system. Therefore, drains should be kept free from any vegetation, by leaving a distance of 30 to 50 cm to avoid any form of blockage (Hui, 2011). Table 3.11 shown the maintenance goals and the required action for green roofs.

Table 3.11. *Green Roof Maintenance Goals and the Required Action* (IMAP, 2014).

Maintenance Objective	Task
Manage lawns	Regular mowing; annual renovation
Maintain trees	Regular pruning, annual tree inspection, brace and support as needed
Monitor plant performance	Maintain records of plant health, vigour and coverage, pest and disease impact, as outlined in a management plan.
Maintain substrate	Top - up of growing substrate may be required due to wind, rain or animal activity (check the depth of the growing substrate before any additions are made to ensure weight loadings are not exceeded)
Maintain drainage	Ensure roof drains are clear and functioning, remove dirt, litter and other deposits from drain inspection chambers, check plumbing hardware, check of condition of filter sheet and deeper layers if necessary
Maintain non vegetated zones	Remove vegetation from perimeter zones and around other equipment and fixtures
Maintain waterproofing	Inspect flashings over waterproofing membrane terminations, inspect the fabric for any damage from water, fertiliser or plants, conduct leak detection of waterproofing on a green roof –if possible

3.2.3. Green Roof Installation and Characteristics

Different types of green roofs may have characteristics in common, which contribute to achieving the same purpose. The best option when choosing a type of green roof is the one that offers low cost and maintenance requirements to eliminate problems. The designer should choose the most appropriate type according to the construction factors and the properties of the roof type. Table 3.12 demonstrates a comparison between the different types of green roofs.

Table 3.12. *Comparison between Types of Green Roofs in Terms of Their Characteristics* (Produced by the Author).

	Intensive	**Semi-intensive**	**Extensive**
Maintenance	High	Frequent	Occasional
Irrigation Process	High irrigation	Moderate irrigation	Low to none
Weight	170–1000 Kg/m^2	170-250 Kg/m^2	50-170 Kg/m^2
	Significant load	Average load	Lightest load
Substrate depth	150 to 1000 mm	100-200 mm	60 – 200 mm
Growth medium	More than 15 cm	12 to 20 cm	Less than 12 cm
Accessibility	Accessible	Not essential	Inaccessible
Biological diversion	High	Medium	Low
Vegetation type	All categories	Limited to grasses, perennials and shrubs	Only grasses, sedums and mosses
Structure support requirements	Necessary	No high demand	Not necessary
Design goal	Can be used as a park / garden	Environmental and aesthetic concerns	Ecological protection layer
Cost	Generally Expensive	Cost effective	Relatively cheap
Flexibility	High	Moderate	Low
Media Type	Concentrated growth media with organic , dense, and low permeability topping	Multi-course	Finer-grained
Attractiveness	Visually appealing	Visually appealing	Not for aesthetic purposes
Prevalence	Less common than the others	Common to some extent	Common internationally

As the types differ, the installation methods also differ. These methods require attention in selection and careful planning, in terms of the used materials and techniques, as they contribute to the success of green roofs for a certain period of time. The proper method of installation provides pre-prepared plans, to any possible problems that could be encountered in the future and to easily provide a suitable solution. The comparison of these methods could be seen in Table 3.13. The most common installation methods are Complete, Modular, and Pre-cultivated vegetated blankets.

Complete

This installation method includes every component in a green roof and provides more diversity for selecting the membrane, plants, as well as the growth medium (Dinsdale, Pearen, & Wilson, 2006). The installation process is done by applying overlapping layers directly over the roof, which offers flexibility in establishing the used layers (Doug, Hitesh, James, & Paul, 2005). This affects the range of plant selection positively. This technique is distinguished by the possibility of installing it during or after the construction. However, this adds to the overall load (DDC, 2007).

Modular

It consists of uniform trays with growing medium. They are grown onsite or offsite, and then installed next to each other to provide complete coverage of the whole roof (Doug et al., 2005). The trays are available in different sizes and depths. However, a thick layer of growth medium is not commonly used. A space between the roof and the trays is usually left to allow drainage and passage of air (Dinsdale et al., 2006). The installation process could be done to a new or existing roof depending on the site and construction considerations (DDC, 2007).

Pre-cultivated Vegetated Blankets

This method includes a thin blanket, which is less than 5.5 cm in depth. The installation process is done by interlocking the rolled up, pre-grown blankets on the roof surface (Dinsdale et al., 2006). Due to its thickness, this method does not provide much flexibility in the selection of plants or membranes, however, this properly makes it a lightweight option (Doug et al., 2005).

Table 3.13. *Comparison between the Installation Methods of Green Roofs* (Dinsdale et al., 2006).

	Installation Techniques		
	Complete	**Modular**	**Pre-cultivated**
Installation	Needs time	Fast	Fast
Repair	Difficult	Easy	Easy
Preparation	On-site	On-site/ Off-site	Off-site
Flexibility	High	Moderate	Low
Specialized companies	Soprema, Hydrotech, Roofscapes	GreenGrid, Green Roof Block	Xero Flor Canada, Elevated Landscape Technologies

1.3. Interior Gardens

As people spend most of their time interior, designing interior spaces by considering the strategies to increase the harmony between architectural elements and users, the level of indoor air quality and user comfort, are essential factors in architectural design (Anderson et al., 2004). Using interior gardens as part of the design of interior spaces creates green interiors and reinforce the relationship between human and nature (Dunnett, Swanwick, & Woolley, 2002). Interior garden is a green area where different vegetation; containing trees and flowers are planted. The sizes, forms, and contents of the interior gardens differ according to the objective of design, as well as the type and the function of the building; such as a hospital, commercial or residential building. These interior gardens help to reduce the pollutants resulting from human activities, and increase the aesthetic aspects of spaces (Falkenberg, 2011).

Figure 3.14. *Interior Garden Containing Trees and Plants, Ankara Airport, Turkey* (Esenbogaairport).

The use of plants in interior spaces goes back to thousands of years in history. For example, Egyptians have used plants for decorating interior of the house 605 years ago. Moreover, Romans created the first botanical garden called "Padua" in 1545. These gardens require extensive knowledge of the types and characteristics of plants and their growth methods (Rayaprolu & Nashipudi, 2016).

Interior Garden Design Considerations

The process of designing interior gardens requires the organization of the plants and other elements in a meticulous and artistic way. Moreover, the factors that could affect the sustainability of the garden should be taken into consideration to ensure a successful design. These factors are categorized as natural and unnatural factors considering the site and space, as shown in Table 3.14 (Momra, 2015).

Furthermore, the type of the building, the design intent, and the possibility for application will determine whether the garden would contain amenities and furniture or serve for environmental and aesthetic purposes (Marcus & Barnes, 1995). It is important to study these factors during the planning and designing phases to avoid possible problems.

Table 3.14. *Factors Affecting the Design of Interior Gardens* (Elastal & El-Materbeai, 2008; Momra, 2015).

Natural Factors	Unnatural Factors
Temperature	Building type and style
Natural light	Design culture
Air humidity	Establishment and maintenance costs
Soil quality	Irrigation system
Vegetation	Used materials

3.4. The Benefits of Vegetated Building Elements

The integration of vegetation in buildings is an ideal approach to take advantage of the properties plants at mostly neglected surface in buildings; such as the roofs or facades, as well as in interior spaces. The benefits of this merge in the infrastructure of buildings are significant, however, it is not commonly applied in traditional buildings (Green-roof, n.d.). This strategy is actually an effective way to meet the needs of people and environment in urban communities, through the sustainable design of buildings. As mentioned in the study of Anderson et al., “designers will need to do the right thing when challenged and continue to accommodate human needs ... by including interior planting in their sustainable designs” (Anderson et al., 2004, p. 3).

The vegetated building elements offer considerable environmental, economic, and social opportunities, which would affect both the public and private sector. “although the benefits are discussed separately, they are actually inseparable and should be appreciated in the built environment” (Loh, 2008, p. 1). The Environmental Protection Agency (EPA) confirms that vegetated building elements, such as green roofs, are one of the best innovative strategies in design. As they mentioned “the large-scale implementation of green roofs will reduce the volume of storm water entering local waterways resulting in less in-stream scouring, lower water temperatures and better water quality” (Green-roof, n.d., p. 5). Plants have great ability to positively influence health as well as struggling against climate change. In addition to these, they also provide benefits regarding financial and aesthetic returns. Hence, they contribute to solving both the current and future environmental problems (Stand & Peck, 2016).

According to a study conducted by the UN experts by the year of 2017 it is estimated that 70% of the world's population would live in urban areas (Roo, Kuypers, & Lenzholzer, 2011). Therefore, the value of plants in buildings and cities must be understood of a global scale in order to increase the vegetation density and to provide building with efficient use of natural resources. The significant success of buildings affects people and the environment, individually and socially (Anderson et al., 2004). Although the application of vegetated building elements is still an issue that need to be developed further, the conducted research by Lee & Maheswaran prove its positive effect on health, climate and air quality (Lee & Maheswaran, 2011).

In addition to that, many studies point out that green spaces help cooling down high temperatures. For instance, an extensive study conducted in 2010, regarding the impact on the environment of the plants used in buildings, found that they are very useful and the results were significantly in favor of urban communities (Zupancic, Westmacott & Bulthuis, 2015). It also concluded that green spaces affect positively on pollution, heat and health, as in Figure 3.15.

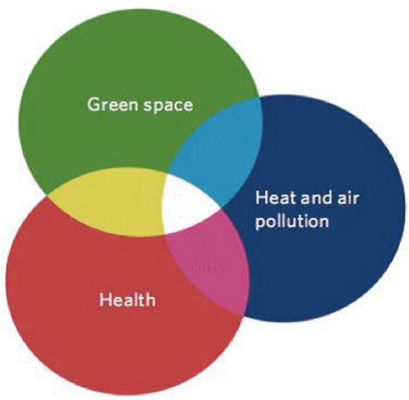

Figure 3.15. *The Relation of Plants with Health, Heat and Air Pollution (*Lee & Maheswaran, 2011).

3.4.1. Energy Efficiency

Vegetated building elements have a significant effect on the thermal performance. Temperature in these buildings is regulated by the natural processes of plants and trees (Li & Yeung, 2014). Plants provide shades to buildings, and lessen the direct sun radiation. According to Oke. (2002), plants have the ability to reflect 50% of sun radiation and absorb more than 80% of it, as seen in Figure 3.16.

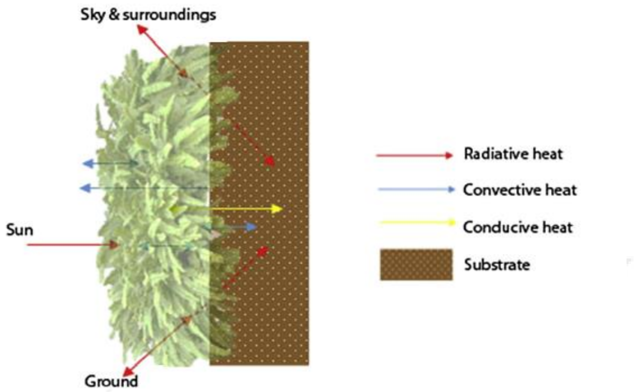

Figure 3.16. *Conductive, Convective, and Radiative Heat of Green Walls* (Oke, 2002).

Moreover, the presence of plants on the surfaces of the buildings creates an ideal insulator for high flow temperatures, together with the air gap found exists between the buildings surface and the vegetation layer. It is possible to mitigate an amount of energy around 2.4 kWh/m^2 with this insulation. Thus, increasing green areas could save up to 20% of the energy used air conditioning. Every decrease in the internal temperature decreases the energy demand by 8% per year (Wong & Baldwin, 2016). On the other hand, as to the vegetation cover at exterior, it is stated that: “increasing tree cover by 25% can reduce afternoon air temperatures by between 6 – 10°C” (Engleback et al., 2003, p. 21).

The evaporation process that plants perform by absorbing water from the soil, distributing it to the leaves, and breathing in stomata leads to cooling of air (Wong & Baldwin, 2016). This process is done by using 60% of the cumulative heat. However, according to Flores Larsen, plants in a humid climate with high speed winds would use 60 to 75% of the cumulative heat for the evaporating process. Furthermore, while plants in a temperate climate with slower wind speeds would use 45 to 65%, the ones in a desert climate would use 23% to 40% of the cumulative heat (Charoenkit &

Yiemwattana, 2016). Table 3.15 illustrates the percentages of reflecting, absorbing, and transmission solar radiation of several plants with different leaf characteristics.

Table 3.15. *Different Plants and Their Percentages of Reflecting, Transmitting, and Absorbing Solar Radiation* (Charoenkit & Yiemwattana, 2016).

Plant	Reflection (%)	Transmission (%)	Absorption (%)	Leaf Characteristics
Elder	22	27	51	Dark Green
Jasmine	24	29	47	Green
Cabbage	25	24	51	Green, Thin, New
Cabbage	23	21	56	Green
Cabbage	30	24	46	White
Cabbage	27	18	55	Dark Red
Maple	24	29	47	Green
Maple	25	34	41	Yellow- Green
Maple	27	38	35	Yellow-Brown
Sheep Sorrel	23	28	49	Green
Burdock	24	24	53	Green
Coltsfoot	24	27	49	Green
Cucumber	23	28	52	Green
Rhubarb	22	24	54	Green
Sugar Beet	24	28	48	Green

Hence, plants eliminate some of the solar radiation by approximately reflecting half of it and absorbing the other half to use it in the evaporation process, in order to cool air, to obtain a successful cooling effect the density and color of plants, as well as the thickness of their leaves should be taken into consideration (Charoenkit & Yiemwattana, 2016). The Zinco firm conducted a research in Germany regarding this issue and it was estimated that: "2 liters of fuel oil are saved per m^2 of green roof per year" (Authority, 2008, p. 17). Another study proved that it was possible to save of 3 to 10% of the fuel bill (Sadeghian, 2016).

> The average daily energy demand for space conditioning caused by the reference roof system … was 6 kWh to 8 kWh. However, the green roof system's growing medium and plants modified the heat flow and reduced the average daily energy demand to less than 2 kWh – a reduction of more than 75 per cent (Authority, 2008, p. 17).

A study conducted in Toronto found that the saving in energy by using green roofs can reduce an amount of energy of 4.15 kWh /m^2 per year, and that is equivalent to a reduction in cost by $22 million (Toronto, 2016). On the other hand, a study in Chicago estimated that if green roofs are applied to cities, an energy saving equivalent to $100 million per year could be provided (Elston, 2000). Moreover, Tony Partingtion states that a building in London with a roof of 850m^2 saved 25,920 kWh per year (Authority, 2008).

Mixed plants and trees have the greatest role in providing thermal comfort and mitigating high temperatures. If more diverse plants were used, the results would be even better (Johnston & Newton, 2004). Five green roofs and five ground-level gardens were studied, and the result was that all cases contributed significantly in mitigating high temperatures in summer, compared to non-vegetated areas. However, the most positive results were in favour of gardens that contained diverse plants. In the same context, a study in Hong Kong confirms a difference of 3.5°C in mitigating temperatures between spaces containing diverse plants and places containing only grass (Zupancic et al., 2015). As stated by Zupancic et al., among the 102 peer-reviewed studies that focus on the effect of plants on buildings, 92% of them proved the positive effect of plants on mitigating temperatures in different spaces, especially on green walls and roofs, as well as in large gardens (Zupancic et al., 2015). Another study conducted in Tokyo shows that green walls could decrease temperatures by 5 to 8°C, as a maximum decrease of 8.4°C, which was achieved during the summer in Hong Kong (Wong & Baldwin, 2016).

A study in 2014 compared a building with green walls and a building with bricks walls in Sheffield, and the result was in favor of the building with green walls as to its performance in mitigating the surface temperature by 9.9°C and air temperature by 3 °C (Zupancic et al., 2015). In Indonesia, Othman and Sahidin examined two buildings, with and without green walls, located on the same site. It was proved that the building with green walls helped in regulating indoor air temperatures, while the other could not (Othman & Sahidin, 2016). Figure 3.17 illustrates the results of this study.

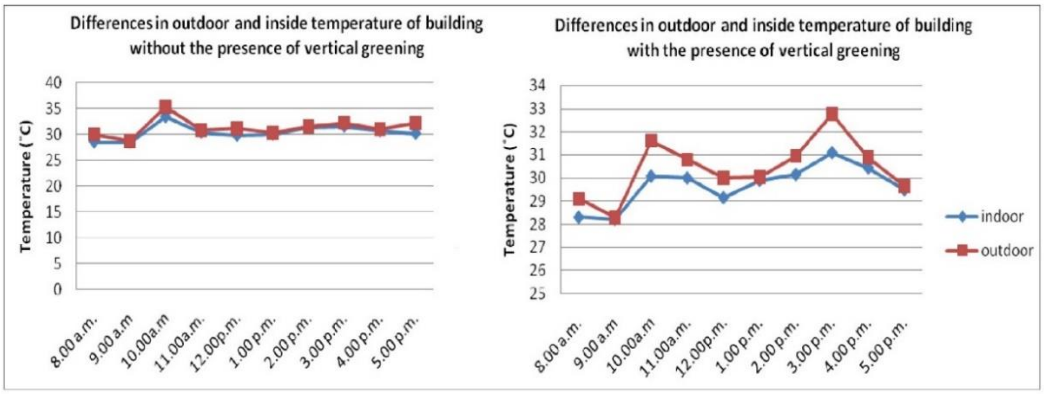

Figure 3.17. *Studying the Impact on the Interior Temperatures of Two Buildings, One with Green Walls and the Other Without* (Othman & Sahidin, 2016).

Selim and Almodovar in 2015 conducted a study in Iraq, comparing green roofs to traditional roofs, regarding their impact on indoor temperature. The results of this study can be seen in Figure 3.18.

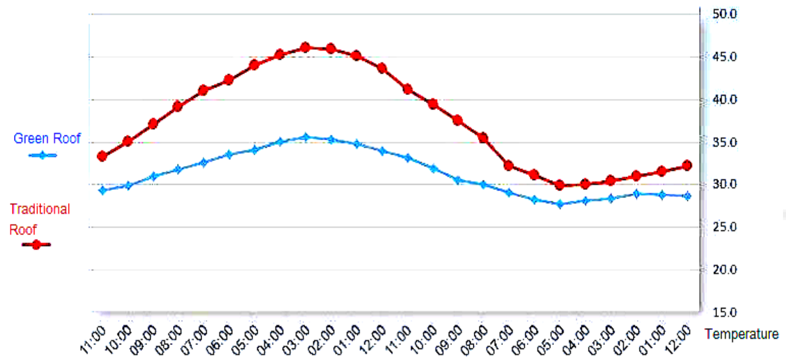

Figure 3.18. *Studying the Impact on Temperature of Green Roof and Traditional Roof in Iraq* (Selim & Almodovar, 2015).

Green roofs have proven their efficiency in thermal comfort also through a study which compared white roofs and green roofs in New York (Susca, Gaffin, & Dellosso, 2011). It was found out that during the hottest period in the day, green roofs gained 1 to 8K less temperature compared to white roofs (Zupancic et al., 2015). On the other hand, in Nottingham Trent University in the United Kingdom, as well as another conducted by the National Research Council in Canada proved the positive effect of green roofs as good insulators for low outdoor air temperatures (Authority, 2008). The following table demonstrates the temperatures under the membranes of conventional roofs and green roofs (Table 3.16).

Table 3.16. *The Result of a Research Study Regarding Temperature under the Membranes in both Summer and Winter* (Authority, 2008).

	Winter	Summer
Mean temperature	0	18.4
Temperature under membrane of conventional roof	0.2	32
Temperature under membrane of green roof	4.7	17.1

According to the study of Charoenkit and Yiemwattana 'investigation' is mostly used for police or a detective's work. The use of plants in building elements contribute to achieving thermal comfort and regulating air temperature in buildings. This feature makes them beneficial tools for providing energy efficiency in the practices of sustainable architecture (Charoenkit & Yiemwattana, 2016).

3.4.2. Improvement of Air Quality

Plants can contribute to improving air quality by eliminating chemical particles through the process of photosynthesis. They capture the pollutants in the air and filter the harmful gases, in addition to producing oxygen and reducing CO_2 (Stand & Peck, 2016). The leaves of plants absorb the air through their stomata and transfer it to the roots. The microbes and bacteria are able to adapt with the chemical pollutants in the air by creating colonies that are resistant to the chemicals (Roo et al., 2011). Through this process, more the plants are exposed to chemicals, more the efficiency in filtering air and converting pollutants into food is achieved.

Moreover, studies have showed that an increase of 10-20% in green coverage would reduce pollutants by 6 grams per cubic meter and produce 27 gram of oxygen per hour (Anderson et al., 2004). In 1985, NASA confirmed the great ability of plants to filter the pollutants in the atmosphere (Loh, 2008). According to the author of *Design for Livable Plants*, 15 to 20 plants are sufficient to filter the air in a 140 m^2 zone. Furthermore, as Wolverton stated; "plants have been found to suck these chemicals out of the air" (Anderson et al., 2004, p. 8). A research published by Greater London Authority in 2004 stated that pollutants in air could be decreased up to 75% by the use of plants with suitable characteristics (Johnston & Newton, 2004). Regarding the function of plants, such studies provide evidence that the usage density is an important factor in affecting the ability of absorbing chemicals such as; NO, SO_2, and particulate matter (PM_{10}). Table 3.17 illustrates the plant characteristics regarding their efficiency in processing air pollutions. For example, a mature tree can capture 1.4 kg of PM_{10}, which is equivalent to the emissions of a car traveling for 20,000 km (Roo et al., 2011). It should be noted that, approximately every 10 cubic microgram increase in PM10, increases the risk of lung cancer by 22% (Zupancic et al., 2015).

Table 3.17. *The Characteristics of Plants in the Efficiency of Processing Some of Air Pollutants* (Roo et al., 2011).

	SO_2 NO_3 O_3	**PM_{10}**	**VOC_S**
Method	Absorption	Impaction	Absorption
Best tree type	Broad leafed evergreen trees.	Conifer trees (evergreen).	Conifer trees
Leaf characteristics	Flat, wide, glossy leaves.	Cone-shaped needles.	Needles with a fatty top layer (cuticle)
Other good tree type	Deciduous tree	Deciduous tree	
Leaf characteristics	Flat, wide, glossy leaves.	Course, hairy, sticky leaves	

Studies have shown that 20% of green roofs in the USA reduce NO_2 by 8000 kg per year, which is equivalent to the amount reduced by 17,000 trees. For the same country, another study states that the absorption of NO_2 by the plants would be 38000 kg per year, if the green roofs were increased by 20% (Rowe, 2011). London Ecology Unit mentions that green roofs have great impact on reducing the level of nitrogen in the air (Authority, 2008). Another study in Chicago states that green roofs reduce pollutants such as PM_{10}, NO_2, and SO_2 by 7 to 27% (Li & Yeung, 2014). In a research which examined 8 green roofs, it was found out that air pollutants could be reduced by 49%, from 247 to 126 ppb, and a maximum reduction of 57% was recorded (Zupancic et al., 2015). The finding of study similar research on the analysis of the reduction of air pollution by the application of green roofs are given in Appendix A. Besides the positive effects of plants used in green roofs for improving air quality, a research conducted in Guelph University in Canada shows the use of green walls have also reduced pollutants such as O-xylene, Ethylbenzene, and Toluene, in addition to reducing significant amount of VOCs in indoor air (Loh, 2008). Another study reveals that using green walls can reduce outdoor NO_2 concentrations by 90%, and PM_{10} by 60% (Pugh, MacKenzie, Whyatt, & Hewitt, 2012). Table 3.18 shows the removal rate of pollutants in Mg per hour for some plants.

Table 3.18. *The Removal Rate of Pollutants in Mg per Hour for Some Plants* (Anderson et al., 2004).

Name Of Plant	Removal Rate (Microgram/Hour)
Boston fern	1863
Dwarf date plam	1385
Bamboo plam	1350
Janet craig	1328
English ivy	1120
Weeping fig	940
Peace lily	939
Areca palm	938
Corn plant	938
Lady palm	876

An experiment regarding the analysis of the indoor air quality at different spots in an office environment, which included a green wall, found that the concentration of VOCs was less than the minimum measurable value of the used device. Therefore, the indoor environment was considered clean and healthy (Brennek, Yuen, & Perkins, 2013).

Indoor spaces containing 50 to 60% plants have better air quality and less potential for diseases than spaces without plants (Anderson et al., 2004). Wolverton stated that: “We have unraveled the mystery of how plants can act as the lungs and kidneys of these buildings" (Wolverton et al., 1989, p. 13). Furthermore, it is mentioned that when dust and pollutants pass through plants from one space to another, they can decrease 20% of those pollutants (Roo et al., 2011). “Two plants per 100 sq ft or two plants per a small office keep the air pure and healthy” (Wolverton et al., 1989, p. 9). Table 3.19 demonstrates the percentage of air pollutant removal by plants over a day.

Table 3.19. *The Percentage of Air Pollutant Removal by Plants over a Day* (Rayaprolu & Nashipudi, 2016).

	Air Pollutant Removal by Plants over 24 Hours							
Plants Name	**Benzene**		**Formaldehyde**		**Trichloroethylene**		**Carbon Monoxide**	
	Initial ppm	Removed %	Initial ppm	Removed %	Initial ppm	Removed %	Initial ppm	Removed %
English lvy	0.235	90 %	-	-	0.174	11 %	-	-
Peace lily	0.166	80 %	10	50 %	20	50 %	-	-
Spider plant	-	-	14	86 %	-	-	128	96 %
Mother-in-law tongue	0.156	53 %	-	-	0.269	13 %	-	-
Golden pathos	0.156	53 %	18	67 %	-	-	113	75 %
Madag dragon tree	0.176	79 %	15	60 %	0.136	13 %	-	-
Heart leaf	-	-	27	71 %	-	-	-	-

3.4.3. Common Benefits

3.4.3.1. Noise Reduction

A proper sound barrier could be created using plants, which would eliminate noise by absorbing sound waves (Sadeghian, 2016). Thus in sense, using plants in building design would be more efficient than using other building materials, as they process the noise coming from the outdoor environment surrounding the building (Loh, 2008). Plants in a small interior space would decrease noise by 5 decibels. Russell and Uzzell conducted a research in England regarding the effect of plants on the absorption of sound waves. It was confirmed that they significantly contributed to noise reduction in internal spaces (Rayaprol & Nashipudi, 2016). In another research, it was proved that green walls decreased noise by 15 Decibels, as well as reducing acoustic echo in interior spaces (Stand & Peck, 2016).

3.4.3.2. Urban Heat Island Mitigation

Urban Heat Island (UHI) is the increase of temperatures in urban areas in contrast to rural areas, having a higher green coverage (Stand & Peck, 2016). This effect on temperature is a result of several factors, such as; climate change, the height, and density of buildings (Roo et al., 2011), as well as the barren streets, open ground spaces, and the rigid wall and roof surfaces in the cities, which absorb the infrared solar radiations (Johnston & Newton, 2004).

Thus, urban cities are experiencing significant increase in temperatures and heat island effect. It is expected that in the next century this increase would be 3-7°C (Pompeii, 2010). One of the studies has found that the increase in temperature can be 9°C higher in London than the surrounding rural areas (Authority, 2008). As a reaction to this increase in temperature, the Environmental Protection Agency has started Heat Island Reduction Initiative (HIRI), which aspires to eliminate urban heat effect through increasing the spread of green coverage and cool roofs (Wong, 2008). Studies regarding the effect of green spaces in summer in temperate and dry climates in Beijing found that they decrease UHI effect by 3.8°C reaching a temperature of 18°C. It was also found that trees can decrease the world's temperature by 5 to 7°C (Armson, Stringer, & Ennos, 2012). Zupancie & Westmacott concluded that; all studies proved the contribution of plants and green spaces in reducing UHI effect and increasing the reflective surfaces would increase the thermal stress and the amount of thermal radiations (Zupancic et al., 2015).

In a research conducted by Alexandri and Jondon in 2006, it was found that air temperature can be decreased by 8.4°C if vegetated walls and roofs were used. Moreover, another study conducted in Japan regarding vegetated walls found that it is possible to reduce UHI effect through evaporation, as well as with the prevention of waves radiating in the environment (reducing of surface albedo) (Zupancic et al., 2015). Figure 3.19 shows the effects of vegetated walls in reducing UHI and thermal radiation. Another research conducted in Singapore proved the positive effects of vegetated roofs by thermal images, as shown in Figure 3.20.

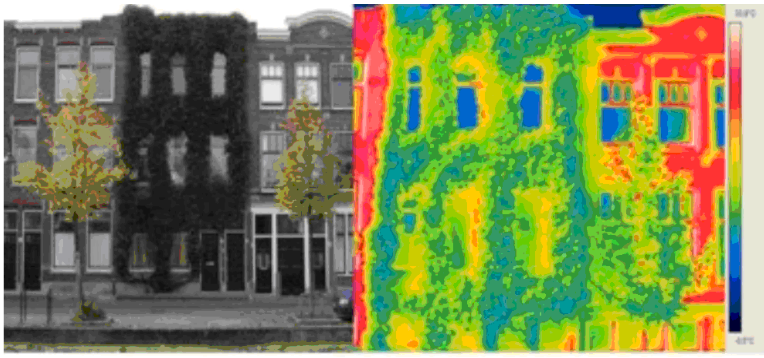

Figure 3.19. *The Effects of Vegetated Walls in Reducing UHI and Thermal Radiation* (Ottelé et al., 2011).

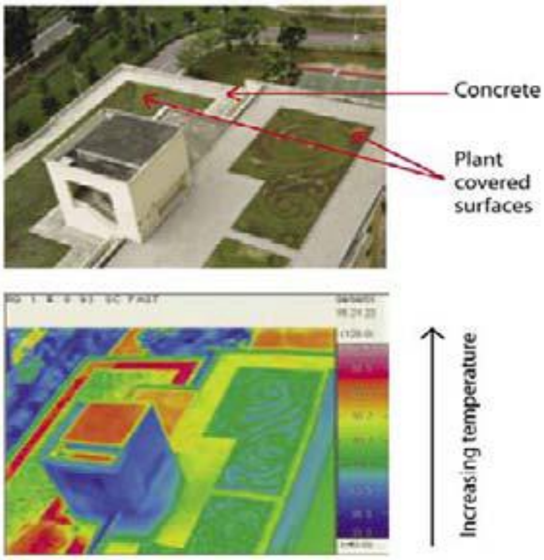

Figure 3.20. *Thermal Image of Vegetated Roof, in Singapore* (Townshend & Duggie, 2007).

New York Heat Island Initiative claimed that implementing vegetated roofs at 50% of urban areas would save 495 million kWh of energy for every one degree reduction of UHI effect (Authority, 2008). According to National Republican Congressional Committee (NRCC), it is predicted that “if only 6 percent of Toronto's roofs, or 6.5 m^2, were green roofs, summer temperatures could potentially be reduced by 1°C to 2°C in the urban center” (Pompeii, 2010, p. 8). Furthermore, a simulation conducted in Toronto proved that application of green roofs at a ratio of 50% would provide a 2°C drop in temperatures (Pompeii, 2010).

3.4.3.3. Improving Health and Well-Being

The amount of plants and green spaces in buildings and urban environments significantly affect the health and well-being (Roo et al., 2011). They reduce stress and increase the mental and physical capabilities through improving air quality, and promoting the visual comfort and aesthetic experience (Shackell & Walter, 2012). The results of Jolanda study indicate that people feel safer when they are in green spaces (Maas, 2009). Plants increase attention, decrease the feeling of fatigue, and lead to faster recovery for patients, as well as decreasing absence of employees due to illness (Loh, 2008). The center of healthy design stated in 2007 that plants promote healthcare. Ulrich confirms that plants contribute to mitigating pain and stress (FSC, n.d.). Moreover, Shakell and Watter in 2012, mention that "even views of greenery through a hospital window can have a therapeutic effect on one's social, emotional and mental functioning" (Shackell & Walter, 2012, p. iii). One of the surveys indicates great satisfaction of employees working in offices containing plants or a facade with a view on green space (Loh, 2008). Another study done in Sweden in 1993 confirms the same results (Shackell & Walter, 2012). Furthermore, in 1999, 12 classrooms in an educational building were studied. An increase in health and comfort by 21% was seen, and a decrease in the illness complaints were noted as a result of using plants in the classrooms (Shackell & Walter, 2012).

Fjeld made a study in Oslo, on 51 offices, some containing plants, while some not. He found that plants improved health at various rates for different symptoms, as demonstrated in Table 3.20, and that the mean value of the improvement percentage was 23% in offices containing plants (Anderson et al., 2004).

Table 3.20. *The Effect of Plants on Improving Health in Indoor Spaces* (Anderson et al., 2004).

Ailment	Reduction %
Fatigue	**20%**
Headache	**30%**
Sore/dry throats	**30%**
Coughs	**40%**
Dry facial skin	**25%**

Another study was conducted on the workers of the radiology department in a hospital, and similar results were obtained, as a decrease of 60% in worker absence due to illness, with the presence of plants in offices was confirmed (Fjeld & Bonnevie, 2002).

3.4.3.4. Protection of the Structure

Tough environmental conditions and climatic factors such as; rain, wind, high temperatures, and ultraviolet radiation effect the life span of building. The direct exposure of the building to these factors may cause damage in the structure and its exterior finishes, such as; material erosion, cracking of building materials, and water penetration (Stand & Peck, 2016). Using vegetated cover for the walls, and roofs could be the perfect solution compared to other costly methods and materials. Used plants are like a shield protecting from direct exposure to acidic rains that cause slow deterioration in the building structure. Moreover, plants would benefit from this water in the transpiration process by absorbing (drinking) it through their roots (Aupetit & Lundberg, 2011). The insulators used in green roofs contribute to maintaining the safety of the structure through preventing water leakage and disposing the unwanted water through drainge. Furthermore, the evaporation process that plants perform is another method to maintain the building’s safety through cooling the surfaces of the structure, and preventing fissures in high temperatures (Timur & Karaca, 2013).

3.4.3.5. Increasing Biodiversity

Using plants with diverse kinds and characteristics contribute significantly to increasing the biodiversity in urban environments (Loh, 2008). The concept of biodiversity in urban environments does not only include the amount of habitable spaces but it also describes the diverse species in these spaces. Spreading of building roofs in cities that contain plants (vegetated roofs) contribute considerably to increasing biodiversity and taking advantage of the natural environment. “Green roofs are one tool for enhancing biodiversity in urban areas” (Currie & Bass, 2010, p. 34). Studies have shown that the depth of the substrate and the used soil in vegetated roofs tackle with climatic conditions and contribute to the life cycle, as well as generating new species of plants, thus, creating abundance in biodiversity (Currie & Bass, 2010). A study in Switzerland found that soil properties in vegetated roofs increase the biodiversity in urban cities, and recommended applying vegetated cover in the new buildings (Brenneisen, 2003).

In addition, vegetated walls are capable of promoting biodiversity and ecological systems through environmental variation. Birkeland proposes regarding taking advantage of vegetated walls in agriculture and food production. Furthermore, the Agro-Housing project in China creates opportunities for producing food in homes (Birkeland, 2007).

3.4.3.6. Aesthetic Value

The design of buildings incorporation plants increases the opportunity for creating appropriate social conditions through providing places for entertainment and recreation. Moreover, it is an ideal method to improve visual comfort, and correcting negative approaches in the city (Stand & Peck, 2016). Vegetated walls contribute aesthetically to the surrounding environment as much as it contributes to the building itself, when a proper and collective planning is done by architects, ecologists and landscapes engineers (Authority, 2008). It has been noticed that direct contact with plants increases the value of the property by increasing the comfort that is reflected from the building, which leads to direct health benefits (Sadeghian, 2016). Also, some buildings may be transformed into remarkable milestones (Timur& Karaca, 2013). Furthermore, plants in enclosed spaces promote visual scenes in the interior design of architectural spaces. A survey study proved that 75.9% of people believe that plants promote the aesthetic value in interior spaces (Rayaprolu & Nashipudi, 2016).

3.4.3.7. Increase in Productivity

Plants affect productivity positively by providing a healthy environment and creating a creative work environment. Two separate studies were conducted in Surrey University and Washington State University indicating that plants reduce work pressure and contribute to increasing productivity (Rayaprolu & Nashipudi, 2016). Furthermore, in a survey done in Texas A&M University it was observed that, in a number of offices containing plants for several months and concluded that plants increased the focus and innovation had increased by 15%, as well as problem solving (Anderson et al., 2004). A similar study showed a 12% increase in the productivity of employees working on computers compared to their colleagues working in offices with no plants (Lohr, 2000). Moreover, a comparison between the productivity in offices with and without plants was performed. It was seen that productivity was less in the offices without plants, due to more recorded absence days by the employees (Bergs, 2002).

In the same context, a study was conducted on 250 employees in a tax office in Holland, and a positive effect on the psychological state of the employees in offices containing plants was noticed, as well as an increase in the quality of work, focus, and productivity (Rayaprolu & Nashipudi, 2016). Odiseos stated that “interior plants are a solid return on investment and a must for any corporation concerned with sustainability” (Anderson et al., 2004, p. 10). Thus, it can be concluded that, several conducted studies reveal the fact that interior plants in work environments have a high asset value. Concerning productivity, to ensure the quality, speed and continuation of work, vegetation at interiors could be implemented, to take advantage of properties of plants in creating a healthy and motivating work environment.

CHAPTER 4

THE POSSIBILITIES AND CHALLENGES OF THE APPLICATION OF VEGETATED BUILDING ELEMENTS

4.1. Climatic Conditions

The climate is defined by Merriam-Webster as "the average course or condition of the weather at a place usually over a period of years as exhibited by temperature, wind velocity, and precipitation" (Merriam-Webster, 2017, para. 2). Whereas weather is defined as "the state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness" (Merriam-Webster, 2017, para. 1). Therefore, typical weather forms of geographical zones are linked when having the same climate, according to the observation of weather for years (Semaan & Pearce, 2016).

As to 'the globalization of agricultural activates' how the weather occurs, how it differ in climatic zones around the world, and the suitable time and place for every specific type of crop become significantly important. One of the main factors affecting plants is the climate of the region. In addition, the duration and quantity of precipitation as well as the average and maximum temperatures of a zone should be known, in order to be able to tackle the difficulties of a climatic zone (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006). As to the weather analysis of scientists, it was noticed that specific types of vegetation grew in specific zones while others cannot. Every climate has soil and vegetation that are closely related to that climate. Hence, it was concluded that vegetation is affected by what is happening in its surrounding environment. Therefore, scientists worked on classifying the environment into certain groups according to the climate of each zone. This classification made the differentiation of climates possible (Halenka, Belda, Kalvova, & Holtanova, 2013).

At the present time, there are several methods for classifying climate. However, the most common classification is Köeppen classification, established by Vladimir Köeppen. Although several enhanced Köppen classifications or new classifications have been published, the original Köppen classification is still the most commonly used classification system (Peel, Finlayson, & McMahon, 2007). As seen in Figure 4.1, this system divides the world into five major categories. The identified letters mostly follows a latitudinal order, starting from the areas near the equator (Category A) to the North Pole (Category E).

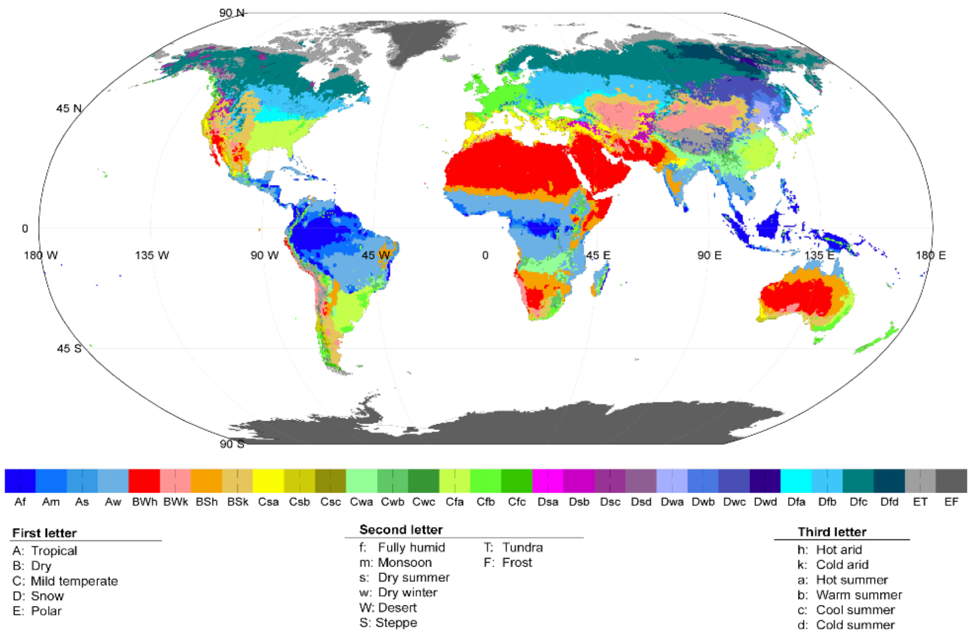

Figure 4.1. *Köppen Classification System of the World Climate* (Chen & Chen, 2013).

4.1.1. Tropical Climatic Zone

These climates are linked to the equator, facing the maximum straight radiation all the year. As a result of this, rainfall and thunderstorms are frequently produced. As the movement of the intertropical convergence zone (ITCZ) brings precipitation is brought to this zone. These climates have regular warm-temperatures due to the consistent solar radiation. In these climates, the mean temperature of the coldest month is 18°C. Hence, all other months are warmer than 18°C (Kottek et al., 2006). Tropical climates have very diverse vegetation. However, the vegetation coverage is considerably more dense (Belda, Holtanová, Halenka, & Kalvová, 2014).

4.1.2. Dry Climatic Zone

These climates are spread at latitudes of 20 to 30° in the subtropics, they generally have moisture deficiency throughout the year. The dryness of climate is identified as the condition when the received precipitation is lower than potential evapotranspiration (ET) (Belda et al., 2014). Aridity of climate does not only depend on the quantity of the received precipitation, the rate of ET and temperature should also be considered. Examples of the area having this climate are central Australia, North Africa, and South-Western United States (Halenka et al., 2013).

Several deserts can exist within these latitudes. Yet, these conditions could be overcome by factor, such as; the warm water of the ocean adjacent to the South-East edge of continent (Todey, n.d.). For example, Florida is in this region. Therefore, it could have been a desert. However, the ocean alters the background flow and makes the climate humid. Consequently, arid climates are located in most of the latitudes where there are lack of rainfalls (Kottek et al., 2006). However, not all the deserts are without plants. Some deserts have dispersed plants, while some are quite lush with rainfalls. Agriculturally, deserts could be very productive areas if they are properly managed and supported with water (Peel et al., 2007).

4.1.3. Mild-Temperate Climatic Zone (Warm Temperate)

These climates are warm, middle latitude climates, between the latitudes of 30° and 40°. Considerable amounts of radiation is received due to the closeness of their location to the equator. Winters are temperate, but summer temperatures are higher (Belda et al., 2014). Generally, precipitation is consistent all year, which make them ideal regions for growing vegetation. Vast growing areas take place in these climates due to their lengthy growing season and abundance of moist (Peel et al., 2007). Major percentage of the world population lives in these climates for their mildness and the availability of water (Todey, n.d.). In these climates, commonly eight to twelve months have an average temperature of above 10°C. Additionally, the temperature of the coldest month is less than 18°C (Kottek et al., 2006). Examples of the areas having this climate are the Mediterranean region, Southern California, and Southern Spain, Many native plants in this climatic zone keep their leaves all over the year, since there is always water in the soil (Halenka et al., 2013).

4.1.4. Snow Climatic Zone

Snow climates are present at farther latitudes than the equator. Precipitation in these climates differs from relatively dry to moist (Belda et al., 2014). Temperature from summer to winter are more extreme than the Mild-Temperate climates. Example region having this climate is Iowa, which is a proper agricultural zone, as it is a more moderate climate (Halenka et al., 2013). Areas such as Canada and Russia in this climatic zone are also vast crop growing zones (Kottek et al., 2006). Generally, four to seven months in this climate, would have an average temperature of over 10°C (Peel et al., 2007).

4.1.5. Polar Climatic Zone

These climates are the farthest northern climates of the ice cap and tundra (Belda et al., 2014). This climate has very few growing plants, only slight vegetation can be grown in these climates as their conditions are significantly severe (Peel et al., 2007; Semaan & Pearce, 2016). Generally, throughout the year, the average monthly temperatures are under 10°C. Nevertheless, one to three months may have an average temperature of over 10°C (Halenka et al., 2013).

4.2. Choosing the Correct Plants

Plants have grown and adapted themselves different environmental conditions since hundreds of years ago (Perry, 2010). They can be seen growing on top of old building roofs, without a growing medium. That is due to some plant characteristics, which enable them to live in a harsh environment. Thus, enabling better conditions for the plants will provide more green coverage. Therefore, the selection of plants according to the design's intent, as well as to climate and plant characteristics, are important to ensure success (Miklós, 1998). It is better to choose plants capable of adapting to different climatic conditions, such as; high temperature, solar radiation, cold, wind, and drought. Also, it is best to avoid plants that are prone to damage by birds and insects, and opt for species with more resistance to diseases and pests (Hui, 2011).

Plant selection requires a comprehensive study of the application site, including the volume and type of soil, irrigation requirements, fertilization, and the orientation of sun radiation, if the goal is to integrate the plants at the exterior of the building. If the aim is to use plants in indoor spaces, other characteristics should be analyzed, such as the amount of light and humidity (Green-screen, 2012). All these factors contribute to reducing the need for maintenance and continuous irrigation, as well as to resisting natural conditions through self-sufficiency. Thus, providing the ideal condition would help to save time and effort, and to achieve sustainability (Townshend & Duggie, 2007). The Nature Conservancy Council mentioned that "low maintenance wild plant gardens on roof tops in the UK could make an important contribution to the survival of Britain's native plants – including rare plant species" (Johnston & Newton, 2004, p. 23). Extremely low and high temperature in some zones can cause damages to some types of plants, and threaten the continuity and success of their growth (Stephen, Noble, Robbins, Wilson, & Mccammon, 2009).

Studies in the field of plants and ecosystems, have provided maps showing appropriate temperature ranges for plants in different zones, which help to in select the plant that has a higher chance of surviving and adapting to the climatic conditions of a targeted area. For example, the map made in 1989 based on the *Sunset New Western* Book, shows 21 different zones in California. Another map, which was developed by United States Department of America (USDA), demonstrates the highest and lowest annual temperatures of 11 zones in North America. These maps have become majorly used references for landscape designers, architects and those interested in this field, to overcome the challenges of plant growth, by selecting the ones that have characteristics appropriate to a particular zone (Perry, 2010). Maps showing the classification of plants and the average annual temperatures for different geographical zones can be seen in Appendix B.

The different need for irrigation by the plants is something that should be studied during the design phase, as plants have different capabilities of resisting drought and to growth for long periods without watering (Li & Yeung, 2014). Some plants can stay in an inactive state for a long period by absorbing and transmitting humidity to overcome hard environmental conditions (You et al., 2016). A study found that three types of plants were able to survive for more than 3 months without the need of watering, which are: Sedum Pachyphyllum, Sedum Clavatum, and Sedum Spurium (Li & Yeung, 2014). Another study examined 123 kinds of plants that have various characteristics. They were subjected to the same conditions but were located in different places, were watered for several days after being planted, and then was left for 4 months without watering. The goal was to measure whether the plants were capable of withstanding drought in natural conditions, especially in places where rainfalls were low. As a result, the plants were divided into three categories: I) Plants that survived and grew normally during the 4 months period without watering. II) Plants that were able to grow but weakly and with problems. III) Plants that were not able to survive without water (Liu, Shyu, Fang, Liu, & Cheng, 2012). The list of plants that are able to resist drought for a period of time without watering can be seen in Appendix C. Plants that are accustomed to solar radiation could be used in outdoor spaces, unlike other plants that are not able to withstand the sun more than 3 hours per day. Some plants can grow properly in indoor and shaded places, while others need sunny location. Some can grow in both types of sites, if appropriate conditions are provided (Li & Yeung, 2014). The effects of increasing or decreasing light on indoor plants, as well as other damaging factors can be seen in Table 4.1.

Table 4.1. *The Possible Causes and Symptoms for Indoor Plant Problems* (Davison, 1998).

Possible Causes	**Foliage**							**Growth**				**Flowers**				
	Brown margins	bend down	yellowish green	oldest drop	all drop spots	spots	wilt	weak and thin	new leaves small	none develops	plant died	fail to develop	color less intense	decline too fast	become smaller	no blooms
Excess light;			•			•	•									
Insufficient light;			•	•				•	•			•	•		•	•
High temperature			•	•			•	•	•			•	•	•		•
Low temperature		•				•				•	•	•				
Lack of water	•			•	•	•	•		•	•	•	•		•		
Too much fertilizer; accumulation of soil salt injuries plant roots, reduces water uptake.	•		•	•	•		•		•	•	•	•				
Lack of fertilizer	•		•	•				•	•			•	•		•	
Compacted Soil; reduces root functions an activity.			•	•			•	•	•			•	•		•	
Low humidity: air too dry to maintain healthy growth.	•	•	•	•	•				•	•	•	•		•	•	•

Using native plants is a significant factor to ensure continuous green coverage in different environments (Benvenuti, Malandrin, & Pardossi, 2016). Native plants are known as the various plants existing for a long period of time in a certain geographical area (Stephen et al., 2009). 72% of authors recommend using native plants by giving scientific reasons as to their resistance to all types of hard environmental conditions, in addition to their ability to dispense pesticides and fertilizers (Butler, Butler, & Orians, 2012). Moreover, some organizations interested in this field have also supported the idea of using local plants, such as Peggy Notebaert Nature Museum and Rana Greek. It should be also noted that, the Environmental Protection Agency (EPA) states "native plants were already adapted to the local conditions; once they are established, they do not need watering, fertilizers or pesticides" (Li & Yeung, 2014, p. 128).

The study of Cantor found that more than half of the vegetated roofs use native plants (Li & Yeung, 2014). Examples could be given as, LDS conference center and PECO headquarters in Philadelphia. Both of them use native plants and grasses that have wide leaves (Sutton, 2013). Dunnett et al., mentioned a concern in using non-native plants, as transferring seeds from one geographical site to another, may threaten its survival, in addition to leading to the extinct of some types of rare local plants (Dunnett et al., 2002; Li & Yeung, 2014). Another study conducted to examine local seeds and grasses in vegetated surfaces in Lincon, Nebraska, which has slight rainfall and unsteady temperature concluded that, native plants are 80% faster in terms of coverage and sedum support in the first year of installation, in addition to providing high economical savings in cost (Sutton, 2013). Some of the native plants regarding specific climatic condition and regions can be seen in Appendix C.

Plants According to the Purpose

It is essential to determine the desired purpose of using plants that are integrated to building elements. If the purpose is thermal insulation and energy saving while providing thermal comfort, it must be known that the plants types to be used for dealing with solar radiation and heat can vary in nature. Plants with high penetration rate and good size are the best for providing thermal comfort in buildings. Studies have proved that the purpose and energy performance are in a strong relationship with each other (Charoenkit & Yiemwattana, 2016). A study regarding the thermal effects of 9 plants, found that plants with heavy leaves, high evaporation rates and high reflection rates perform better in reducing temperatures compared to their surrounding areas, as shown in Figure 4.2 (Liu et al., 2012).

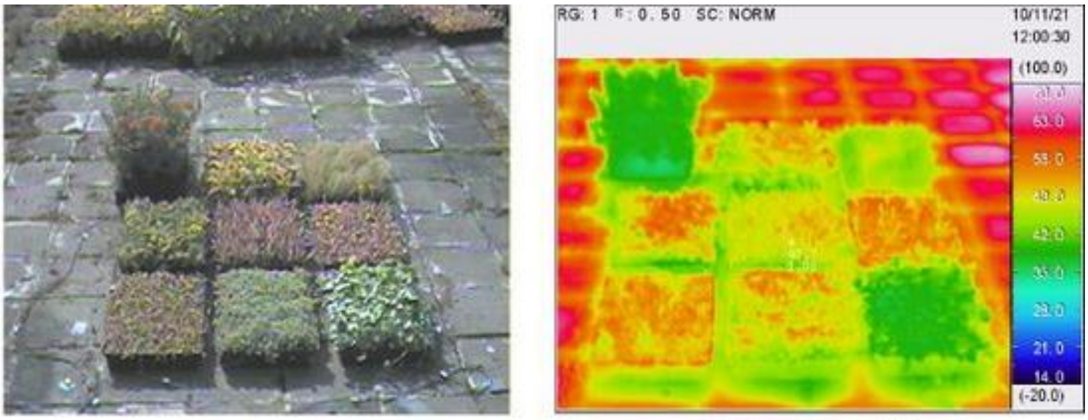

Figure 4.2. *Thermal Image for Plants of Several Characteristics That Show Different Capabilities of Providing Thermal Comfort* (Liu et al., 2012).

As to the aesthetic purposes, plants with various colors and shapes could be used with a coverage that achieves harmony with the building design. In order to ensure suitable conditions for plant growth, some materials and conditions should be provided, which could affect the design. For example; English Ivy, is for horizontal coverage. To make it vertical, the cable should be connected directly to the walls, and each cable should have one plant, while other systems of vegetated walls use panels for unlimited number of plants (Green-screen, 2016). Self-clinging plants could be used to eliminate the use of installation panels in walls. (Green-screen, 2016) In vegetated roofs, using small plants need more care than other large plants used in wide roofs, which do not require nutrition, trimming and watering (Lennep & Finn, 2008). Thus, the style of plant growth, shapes, and their needs in installation contribute to the aesthetic value of the building design. Other purposes in construction, such as reducing pollutants, increasing health etc., could be achieved by using different types of plants capable of withstanding local conditions. Appendix D shows a list of suitable plants and their characteristics for green roof and wall systems.

4.3. The Vegetated Building Elements Policies and Incentives

Enabling the application of environmentally friendly projects is in fact, the responsibility of a very large population, including researchers, professionals, politicians, and even the society (Aupetit & Lundberg, 2011). The use of plants in building elements, such as, green roofs, walls and interior gardens, would contribute to mitigating environmental problems, health urban areas, which can be consider as an achievement of sustainable living, also to be treasured by future generation. (Anderson et al., 2004; Lennep & Finn, 2008). Numerous organizations and governments have realized the capability of plants to reduce pollution and mitigate high temperatures, in addition to their other benefits (Liu et al., 2012). Thus, they have presented many initiatives and incentives with the intention of increasing the level of awareness in the community and to encourage the application of these projects in both public and private sector (Green-roof, n.d.). The methods of promoting the use of vegetated building elements differ across the various stakeholders, either to be in the shape of direct or indirect incentives, voluntary procedures, or command and control (Clark, 2008). These methods include the intensification of information, research, conferences, training, and providing financial rewards to the owners of these buildings (Stand & Peck, 2016).

The Environmental Protection Agency (EPA) has offered a number of initiatives throughout the years, including HIRI, NDDES, and Clean water Act, to address issues such as, high average temperatures, climate change, pollution, and management of storm water, which offer to overcome these problems through the use of vegetated cover in urban environments (Green-roof, 2016; Pompeii, 2010). In 2001, the American Society for Testing and Materials (ASTM) created the group GRST, to establish green roofs standards, referred to as WK14283, which identifies to identify the techniques, concepts, and principles of applying green roofs (Green-roof, 2016).

Moreover, rewards and certificates are provided for promoting the evaluation of the performance of buildings and their influence on the surrounding environment, which should actually be considered as a social responsibility (Süzer, 2015). The green building council in USA SGBC, provides an environment-friendly building certificate system, which is known as LEED. The application of green roofs and walls can help a building to have such a certificate, as they are rewarded by collecting points for the used techniques (Stand & Peck, 2016). The building of California Academy of Sciences, which used wavy roofs covered with native plants, received a LEED Platinum rating, as well as other rewards from American Society of Landscape Architects and Green Roofs for Healthy Cities (GRHC) (Butler et al., 2012).

Various organizations and authorities worked on increasing the level of awareness in the benefits of projects including vegetated building elements, through research, studies, and advertisement. For example, Toronto city provided advertisement campaigns regarding green roofs through training, workshops, and presenting lists of suppliers and contractors. Furthermore, to present the successful exemplary projects and previous studies between the years 2008-2009, conferences were help (Townshend & Duggie, 2007). Also, establishing exhibitions and continuous training courses and research regarding green roofs and walls by organizations, universities, and companies such as: GRHC, NGA, and Gallup organizations, Ryerson and Toronto Universities were established (Currie & Bass, 2010; Green-roofs, 2016). Chicago Urban Land Institute Non-profit organization has participated in several studies and seminars to help determining the type of appropriate incentives and encouragements for the use plants with a sustainable approach, in addition to the support of informatics to provide help through the city's website. Moreover, Basel city in Switzerland established a contest to determine the best green roof (Townshend & Duggie, 2007). On the other hand, as a result of the encouragement programs in North America today, there are more than 6000 certified trainer for green roofs (Green-roof, n.d.).

The 'command and control' methods managed by governments and municipalities, are the policies to promote the sustainability of cities. A member of the Minneapolis city council in USA stated that:

> Elected officials and politicians across America, or only in progressive cities, need to embrace green walls and roofs as best management practices in government approvals process. Approval authorities should consider the inclusion of these amenities as alternative compliance for greening requirements (Green-roofs, n.d., p. 6).

The Mayor of London stated that "living roofs and walls will be incorporated where feasible and reflect this principle in Local Development Framework (LDF) policies, and this will include roof and wall planting that delivers as many of these objectives as possible” (Lennep & Finn, 2008, p. 37). He also mentioned that “boroughs should also encourage the use of living roofs in smaller developments and extensions where the opportunity arises” (Lennep & Finn, 2008, p. 37). Several authorities provided incentives and grants to support green roofs, walls and interior gardens in buildings, as given in Table 4.2. Table 4.3 illustrates a number of policies and laws imposed by different authorities on building owners.

Table 4.2. *Examples of Incentives for the Use of Vegetated Building Elements in Several Countries* (Produced by the Author).

	City	Title	Year	Policy / Plans States
Canada	Montreal, Quebec,	Montreal master plan	2002	Supporting the public and private sector. When applying green roof, Gaz-Metro gives 56$ Cdn/m^2. (Lawlor, 2006).
	Toronto, Ontario,	Incentive pilot program	2006	Roofs that are covered by vegetative more than 50%, are given 10 $ Cdn/ m^2, until a maximum of 20 thousand dollar (Clark, 2008).
	Vancouver	Planning Policy	2005	A plan for promoting the application of green roofs in 50% of buildings in a neighborhood in Vancouver (Lawlor, 2006).
	Austin, Canada	Canadian School Gardens Grant Program	2014	A grant of 2000$ is given to schools for growing several plants in schools gardens (Whole foundation, 2016).
Germany	Berlin	Storm water fee	1980	There is a bill containing a storm-water fee by water utilities. However, the green roof is given a discount if it contains storm-drains (Clark, 2008).
	Bonn	Storm water fee	-	1.03 €/m^2 is saved every year when applying green roof (Clark, 2008).
	Cologne, NRW	Wastewater fee bylaw of 14.12.2003	2003	Every green roof get a discount depending on its run-off coefficient from the basic fee, which is currently 1.10 €/m^2 per year (Ngan, 2004).
	Stuttgart	financial incentive	1986	An annual fund is allocated to building’s owner by paying 50% of green roofs construction fees, up to 25$/m^2 (Townshend & Duggie, 2007).
	Frankfurt, Kassel, Leonberg	financial incentives	2001	Financial incentives from 25-100% of construction cost, equivalent to 5-50 € (Engleback et al., 2003).
	State of North Rhine Westphalia	Initiative for Water management	1999	Funding of 15 €/m^2 is given to green roofs that have run-off coefficient more than 0.3 in urban areas (Clark, 2008).

Korea	Seoul	Regulation on the promotion green tract	2002	The government pay 50% of the cost of building green roofs to promote the spread of green areas (Clark, 2008).
United States of America (USA)	Chicago, Illinois	Green roof policy	2005	Planning and Development Department support permit procedure, and 5000$ are given to green roofs of small buildings, commercial or residential (Townshend & Duggie, 2007).
	Minneapolis, Minnesota	Code of ordinance	2005	The owner pays fee of storm water depending on the percentage of green coverage (Clark, 2008).
		Storm water credit program	2000	Discounts are given, until 100% of the fees for storm water in buildings applying green roofs (Ewing et al., 2013).
	Portland, Oregon	Green building policy	2001	Projects owned by the city are supported to be eco-projects, so more than 70% green coverage should be in roofs. These roofs are eligible for discount by 35% on storm water fee (Townshend & Duggie, 2007).
	Milwaukee	Regional green roof Initiative	2010	The owner of green roofs will be given 55 $/ m^2 (Ewing et al., 2013).
UK	London	Policy on living roofs	-	Lanching GRO guide that covers all the requirements of green roofs; choosing, designing, installation to ensure the success and sustainability (Sheffield, 2011).
Singapore	-	Planning system	-	Green roofs are encouraged by not calculating the green area as part of the total area of the building (Greenroof, 2016).
	-	supportive government policies	-	There is strong support from government for the spread indoor gardens in Asia in the future plan (Larson, 2016).
Australi	Sydney	Green Wall Policy	2014	Spreading awareness and research regarding green walls, and indoor gardens, and installing them on public buildings (Council of Sydney, 2014).
Switzerland	Basle	Basle incentive program.	1990	1 million dollar was invested to give incentives of 20 $/m^2$ of green roofs for 2 years (Townshend & Duggie, 2007).

Table 4.3. *Examples of Policies for the Use of Vegetated Building Elements in Several Countries* (Produced by the Author).

	City	Title	Year	Policy/Ordinance/Plan States
Austria	Linz	The Green Space Plan	2001	New buildings with a size of 100 m^2, must have 80 % vegetation covered roof, as long as it is 20 degree slope. With more than 30% native soil (Ngan, 2004).

England	Sheffield	Green Roofs (PUD 8)	2007	Buildings larger than 1000 m^2 should contain 80% green covered roof (Clark, 2008).
Germany	Berlin	Biotope Area Factor	-	Commercial projects must have 30% green cover, while residential must have 60% in 13 areas of Berlin (Clark, 2008).
	Munich	-	-	Any roofs larger than 100 m^2 must be green covered (IMAP, 2014).
Japan	Osaka	Promote Greening in Buildings	2006	Building with an area of at least 1000 m^2 requires green coverage (Hajime & Lee, 2007).
	Tokyo	Regulation on Protecting the Nature	2001	Both of public sector buildings that are more than 250 m^2, and private sector buildings, which are larger than 1000 m^2, must have 20% green coverage of the roof and site (Authority, 2008).
Korea	Busan	Regulation on Support of Green Roofs	2004	Both of public sector buildings that are more than 150 m^2, and private sector buildings, which are larger than 200 m^2, must have 20-30% green roof coverage (Clark, 2008).
Switzerland	-	Federal Law	2002	Any new or renewed building should have green coverage to capitalize biodiversity in urban cities. (Clark, 2008).
Denmark	Copenhagen	Policy on sustainability incentives	-	Roofs having pitch of 300 or less must be green covered (IMAP, 2014).
China	Beijing	Policy Targets	2008	A plan aims to achieve green coverage for 60% of buildings less than 12 floors, and 30% for high buildings (Authority, 2008).
United States of America (USA)	Seattle, Washington,	Seattle Green Factor	2007	Any building in a commercial area must have 30% coverage from green roofs, walls and gardens, according to 122311 Ordinance (Sharp et al., 2008).
	Washington	Sustainable DC Plan	2013	New buildings are required to achieve environmental sustainability, the owner is allowed to choose building methods, including green roofs and walls to reach a certain score of GAR (Stand & Peck, 2016).
	Philadelphia	Green City, Clean Waters	-	The water department of Philadelphia made an investment plan for green infrastructure instead of the traditional one, which provides 25% of green roof construction cost until a 100,000 $ (Green roof, n.d.).
	Chicago	the Energy Conservation Code	2001	The policy of saving energy requires new and renewed building to use roofs with low reflecting factor including green roofs (Townshend & Duggie, 2007).

CHAPTER 5

THE ANALYSIS OF THE LEVEL OF AWARENESS AND THE POSSIBILITY OF APPLYING VEGETATED BUILDING ELEMENTS

5.1. Methodology

A questionnaire which analyses the possibility of applying vegetated building elements (green roofs, walls and interior gardens), and the level of awareness of academics and professionals in the field of construction regarding their benefits, was conducted. The study was conducted between the 5th of April and 4th of July 2017 on professionals related to the mentioned field, which include; Architecture, Civil Engineering, Urban Design, Urban Design, Planning, Agronomy, and Investors. The participants represent different views from the public and private sector, which affects the environmental and economic future development of cities and urban communities. This study took place in different countries (Turkey, Libya, Canada, and Malaysia) with four different climatic zones, excluding the polar climate as this zone lacks buildings. These countries were chosen for their different climatic conditions and various policies and regulations, which represents a comprehensive overview related to vegetated building elements. Another reason is the ease of communicating with targeted participants in these countries. The questionnaire was distributed evenly as 15 copies to each zone. In total 60 responses from four climatic zones, with weighing of 60% professionals and 40% academics was gathered, as seen in Table 5.1. A copy has been sent to each participant as an email in both Arabic and English language.

Table 5.1. *The Details and Classification of the Participants*.

Country	Enterprise	Sector		Participants				
		Private	Public	Distributed	No reply	Refused	Acceptable	Total
Turkey	Çankaya University	•		31	22	0	9	15
	Karabük University		•	12	7	1	4	
	Selçuk University		•	5	3	0	2	
Libya	Alemara Inc.		•	20	8	1	11	15
	Tattwer research Company	•		5	1	0	4	
Malaysia	Teknologi MARA University		•	7	4	0	3	15
	Sains Malaysia University		•	9	5	0	4	
	Tun Hussein Onn University		•	5	2	1	2	
	Eco-outdoor Company	•		13	12	0	1	
	Lush Eco Sdn Bhd Company	•		21	16	0	5	
Canada	Living Wall Inc.	•		8	7	0	1	15
	GSky Company	•		20	17	0	3	
	Ambius Company	•		5	4	0	1	
	BH-Architects Office	•		11	10	0	1	
	Bldg Office	•		15	15	0	0	
	Sedum Master Company	•		9	8	0	1	
	Xero Flor Canada	•		8	6	1	1	
	Restorations Gardens Company	•		4	4	0	0	
	Live-Roof Global	•		6	5	0	1	
	Vitaroofs Inc	•		12	8	2	2	
	ZinCo Inc.	•		6	5	0	1	
	Mayhew Inc.	•		5	4	0	1	
	A.M.A. Plastics Ltd	•		19	17	0	2	
Total				**256**	**190**	**6**	**60**	**60**
%					**74.2**	**2.3**	**23.5**	

Questionnaire format

Regarding the type and context of the questions, the questionnaire was divided into three sections: i) Personal information, ii) the general perception, and iii) future perception of vegetated building elements, a copy of the questionnaire can be seen in Appendix E. A similar approach is used in many research and academic studies, such as in the Master thesis of Gündoğan conducted in METU University (Gündoğan, 2012). All questions are based on a comprehensive study on the literature review related to the mentioned topic. Furthermore, the questions were designed to be clear to avoid any possible hesitation while answering, which include multiple choice, and ranking questions to see the level of compatibility, and preference of participants related to certain issue.

Data collection and analysis

The questionnaire was conducted online via Google Forms, which is a specialized website for creating questionnaires and surveys with providing responses collected in an online spreadsheet. The analysis of the questionnaire was done by Excel programme, in addition to Statistical Package for the Social Sciences (SPSS), which is the most popular software used in analysing digital data through reading the entered data and extracting results in the form of statistical reports and graphs to obtain clearer and more precise results. After that, the obtained results are discussed and compared with previous studies.

5.2. Findings of the Study

The 60, academic and professional participants included in this study were distributed evenly over four countries: 25% from each country; Libya, Turkey, Canada, and Malaysia, to have a uniform distribution on the four targeted climatic zones of Köppen climate classification. All the participants were chosen from professions most related to the application of vegetated building elements. The highest profession percentage was architecture with 30%, followed by 15% for both civil engineering and urban design, 17% for landscape design, and 12% planning engineering, 8% investment, and only 3% for Agronomy, as shown in Figure 5.1.

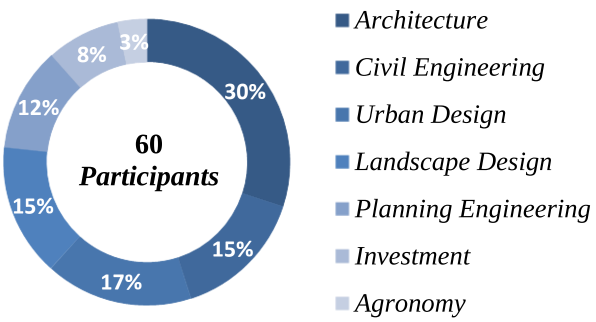

Figure 5.1. *Data of Professions of the Participants.*

Personal information of participants

The work experience differed among participants, where almost half of them had experience ranging from 5-10 years, 25% had less than 5 years of experience, 18.3% had 11-15 years and 10% had more than 15 years of experience. In terms of the number of completed construction projects, most participants, with 40% took part in 5-10 projects, 30% was in less than 5 projects, 23.3% was in 10-20 projects and 6.7% contributed to more than 20 projects, as shown in Figures 5.2 and 5.3.

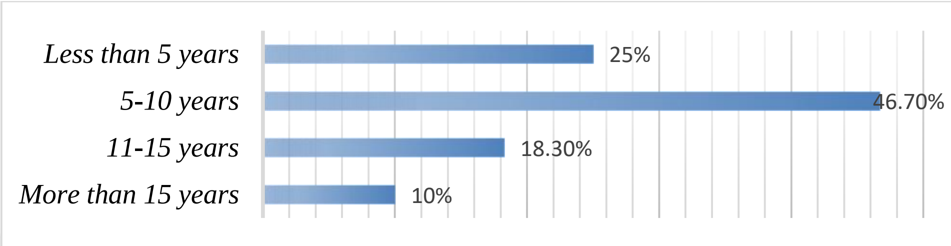

Figure 5.2. *Years of Experience of Participants.*

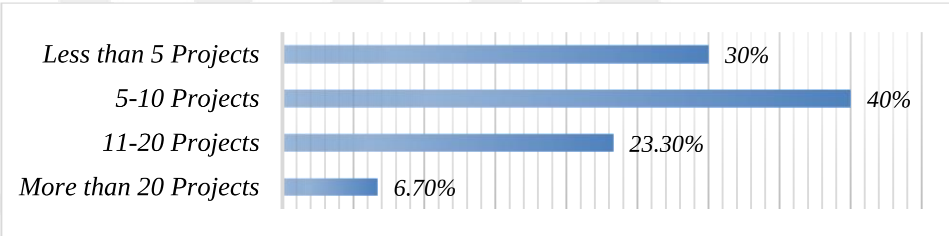

Figure 5.3. *Number of Projects of Participants.*

Most of the participants (93%) have knowledge on vegetated buildings elements, and 77% of them have participated in the design and construction of green roofs, walls and interior gardens in buildings. More than half of participants received their knowledge through the internet. This is apparently the best and easiest method for those interested in gaining knowledge on the issue. This method is followed by field experience (51.7%), as to the projects they have participated in, during their work in this field, and then by colleagues with 46.7%. The participants who were interest in developing their knowledge through attending specialized courses had a percentage of 41.7%, whereas, attending related conferences had 31.7%. The lowest percentage was to acquire knowledge through advertisements (26.7%), as seen in Figure 5.4 and 5.5.

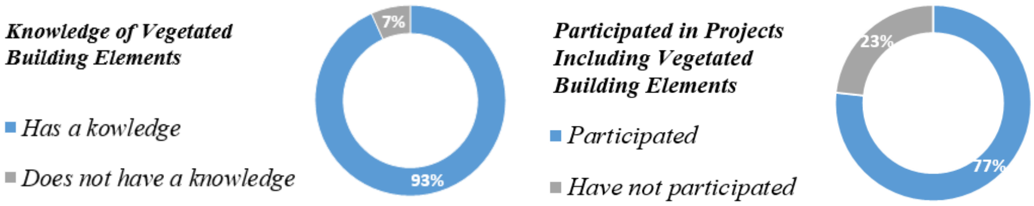

Figure 5.4. *Knowledge of Vegetated Building Elements of Participants and Their Contribution in Application.*

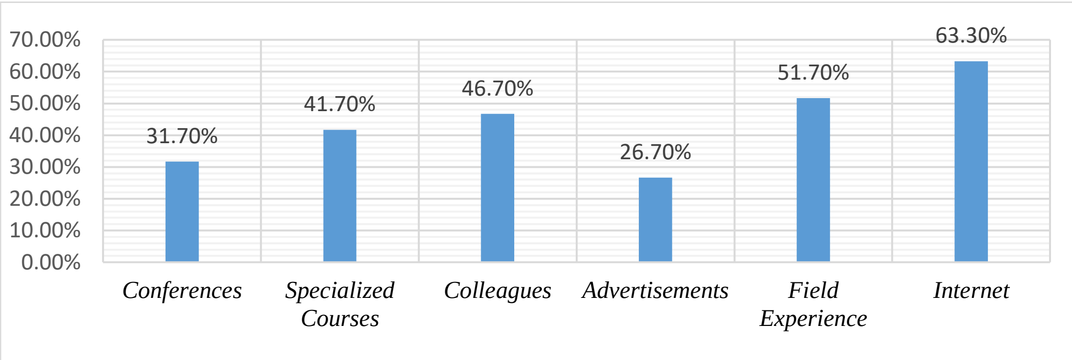

Figure 5.5. *Sources of Knowledge of Participants.*

Plants benefits and their application for different construction methods

43.3% of participants have sufficient knowledge of plant functions and their benefits in buildings, while 28.3% have comprehensive knowledge on the issue. A large percentage of them believe that there is a great opportunity for the integration of plants with the building elements when the construction method is concrete. This is most likely because concrete structures are more resistant to humidity and loads (OCCDC, n.d.). 86% think that vegetated building elements are applicable for steel structures, while only 7% believe that they are applicable in timber frame structures, as shown in Figure 5.6 and Figure 5.7. This result is relatively consistent with the finding of the conducted literature review, as where the design and application of green walls and roofs require thorough examination and detailed calculations of structural engineers to ensure appropriate load bearing systems in the building (Sharp et al., 2008). Different systems of green walls, roofs and interior gardens which vary in characteristics and application methods provide several options for designers according to the resistance of building structures. Shackell and Walter stated that: "most of garden projects will require input from a design professional, and it is always advisable to employ a designer who has had some formal training in this field" (Shackell & Walter, 2012, p. 17).

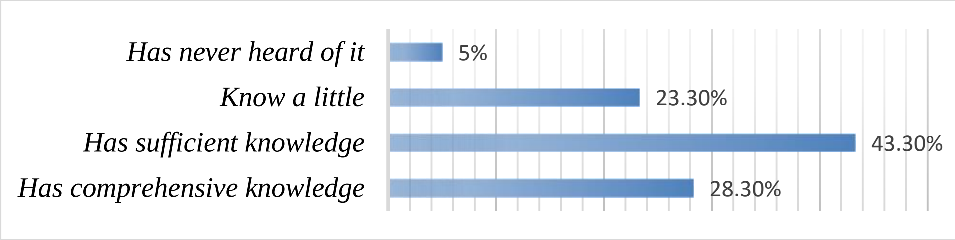

Figure 5.6. *Knowledge about the Function and Benefits of Plants in Buildings.*

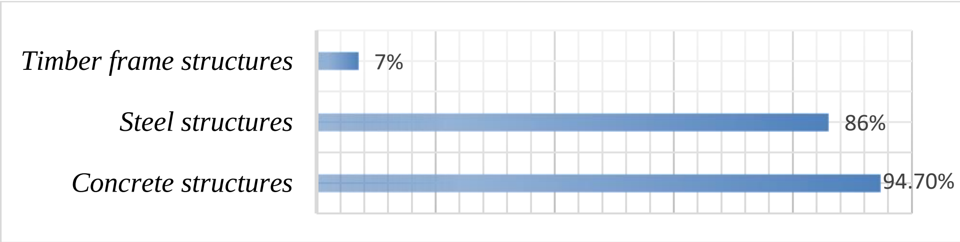

Figure 5.7. *The Possibility of Application for Different Construction Methods.*

The significance of professions and the different type of buildings

Regarding the significance of the application of vegetated building elements for different types of buildings, the majority of responses ranked health care building first. This is most likely due to the role of plants on the health and psychology of patients and visitors, as there are numerous research encouraging the integration of plants in this type of buildings, such as the application of in hospital gardens, called the "Healing Gardens" (Hartig & Marcus, 2006). A user of such a garden for cancer treatment in London stated: "The garden in health care buildings; sometimes that's more valuable than any medicine" (Shackell & Walter, 2012, p. 8). Moreover, commercial buildings and hospitality buildings were ranked second and third, respectively. This is possibly because they are buildings which could benefit the most, as they use a lot of operational energy throughout the day. Therefore, constructing a sustainable architecture should be considered among their management plan to save energy and reduce costs in the long term, as well as for strategic marketing purposes. This approach is consistent with the statement of Anpetit and Lundberg "green walls in case of a commercial building they can increase the public's frequentation ... Green walls make building noticeable, so they can be a marketing toll" (Aupetit & Lundberg, 2011, p. 12). Moreover as to resilience, it was concluded that green roofs economically outperform standard roofs over their lifespans (Tassicker, Rahnamayiezekaret, & Sutrisna, 2016).

On the other hand, residential buildings were ranked fourth. This result is consistent with the finding of a questionnaire conducted by Stand and Peck in 2015, on regarding the application of green walls on different types of buildings in USA. It was found out that residential buildings are of a less importance due to the relatively high cost. However, regarding the importance of institutional buildings, there is a contradiction, since participants in this research ranked them as one of the less important buildings, while the research of Stand and Peck ranked them the most important (Stand & Peck, 2016). Thus, more research on the application of vegetated building elements on institutional buildings could be determinative in clarifying their importance. The significance of the application of vegetated building elements for different types of buildings, according to the respondents can be seen in Figure 5.8.

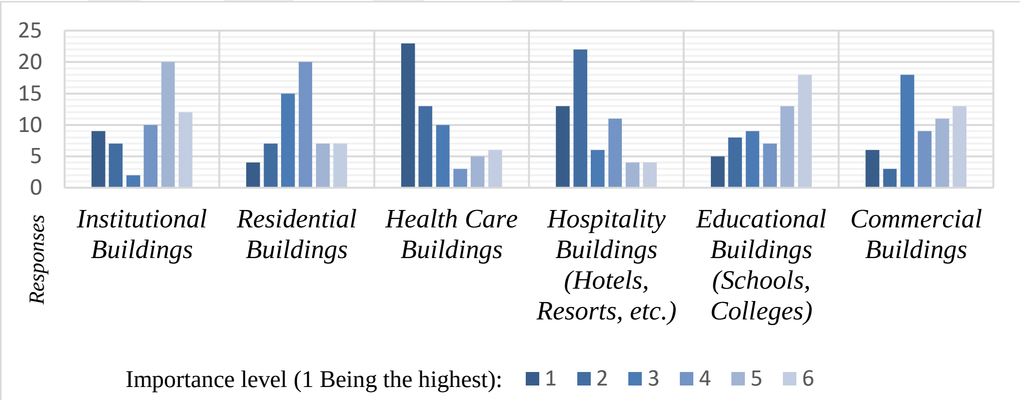

Figure 5.8. *The Significance of the Application of Vegetated Building Elements for Different Type of Buildings.*

The professions were ranked according to their significance in managing and implementing vegetated building elements, as; architect, environmental engineer, landscape designer, urban planner, civil engineer, project owner, financial expert and information technologist, in descend order of significance (Fig 5.9).

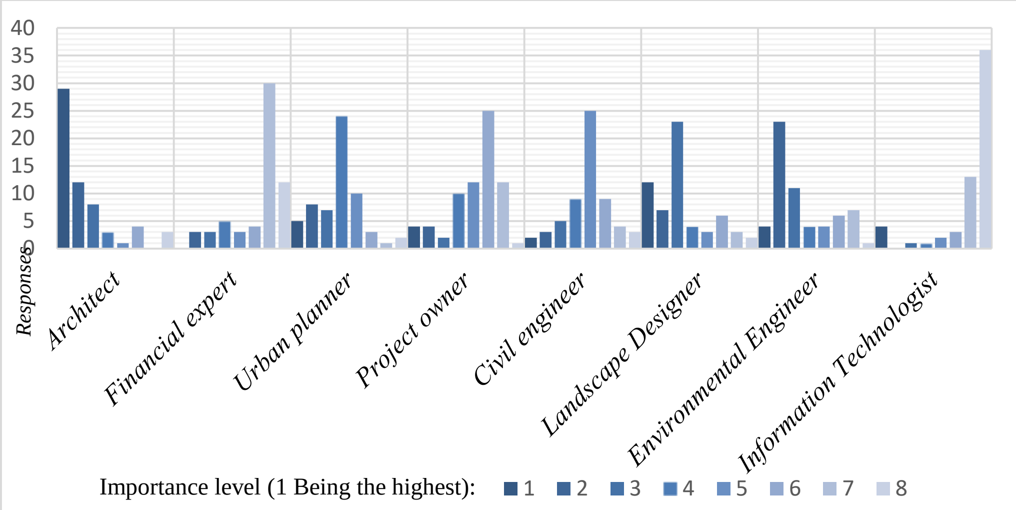

Figure 5.9. *The Significance of Professions in Managing and Implementing Vegetated Building Elements.*

About two-thirds of the participants thought that it is definitely possible to design structures capable of withstanding large loads of green roofs, while 33.3% felt that it is possible to a certain extent, as seen in Figure 5.10. This implies that loads are not a barrier to the application process for new buildings. However, live and dead loads, such as the wind, growth medium, and rain loads should be studied, in addition to estimating the load and size of plants for their future growth (Hui, 2011; Miklós, 1998).

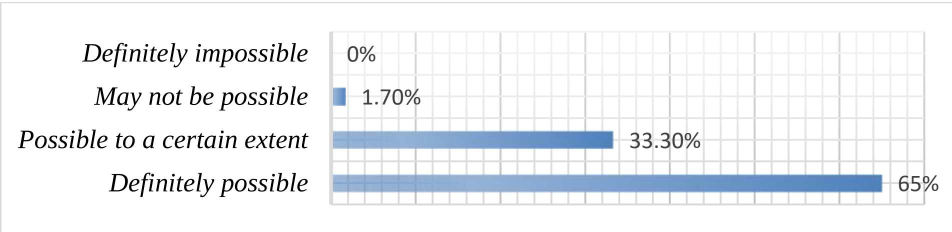

Figure 5.10. *The Possibility of Designing Structures Capable of Withstanding Large Loads of Green Roofs.*

The application on historical buildings

Another point related to the possibility of applying vegetated building elements to historical buildings, is that large number of respondents thought it is possible to a certain extent, according to the situation of the building structure and the type of vegetated elements, while 20% considered it definitely possible, and 18.3% though it was not possible. This result is consistent with a report of United State General

Services Administration published in 2011, as is was stated that, some historical buildings containing vegetated building elements, had strong well-engineered, structures with high quality. Thus, these buildings provided a good opportunity for the application process of vegetated building elements (GSA, 2011). National Gardens Service of U.S. Department of the Interior has published guidelines regarding the sustainability for the rehabilitation of historical buildings. The possibility of applying vegetated roofs on historical buildings could be seen in this report, by underlining some aspects that should be taken into consideration regarding this issue (Grimmer, Hensley, Petrella, & Tepper, 2011). The possibility of applying vegetated elements to historical buildings according to respondents is shown in Figure 5.11.

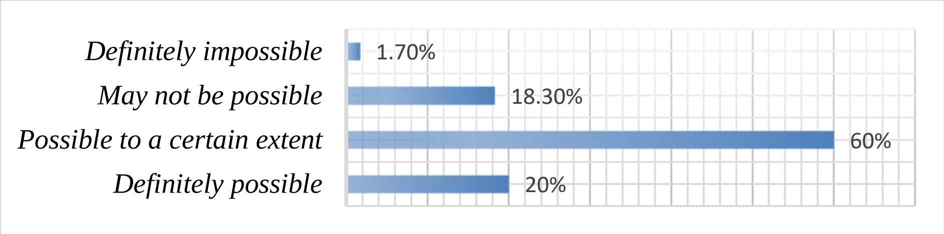

Figure 5.11. *The Possibility of Applying Vegetated Elements to Historical Buildings.*

The importance of maintenance

Almost two-thirds of the participants believe that the vegetated building elements certainly need periodic maintenance, as shown in Figure 5.12, which is strongly consistent with the results of the conducted literature review, such as the studies of Sharp et al., (2008), Hui (2011), Lennep and Finn (2008), and Wilkinson et al., (2015). However, it was mentioned that there is a variation in maintenance requirements for different systems of green walls and roofs; as some types require periodic maintenance only through the first year of installation (IMAP, 2014). Elgizawy concluded that all categories of the green walls achieve the same purpose, but the difference lies in the ability of growth, survival and maintenance (Elgizawy, 2016). In addition to that, the type of used plants and surrounding conditions are important factors in determining maintenance requirements (Townshend & Duggie, 2007).

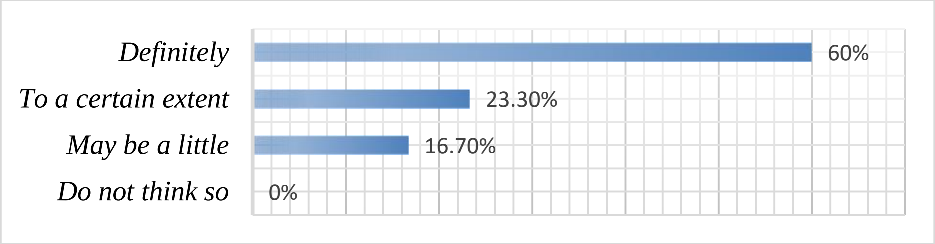

Figure 5.12. *The Importance of Periodic Maintenance of Vegetated Building Elements.*

The architectural layout and energy efficiency

More than three-quarters of participants believe that interior gardens positively affect the architectural layout of buildings. Moreover, more than two-thirds believe that vegetated building elements contribute to energy efficiency and reducing costs in buildings, which is consistent with what is mentioned in previous chapters (Figures 5.13 and 5.14).

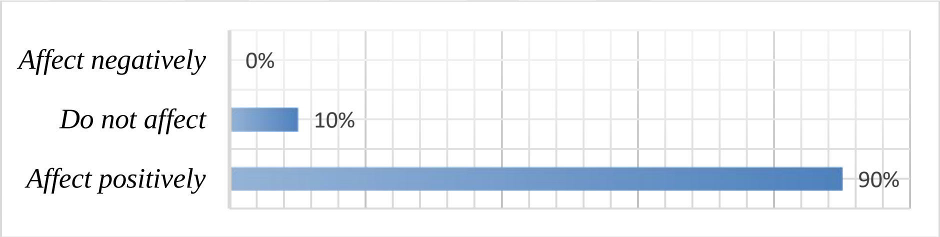

Figure 5.13. *The Effect of Vegetated Walls and Interior Gardens on the Architectural Layout of Buildings.*

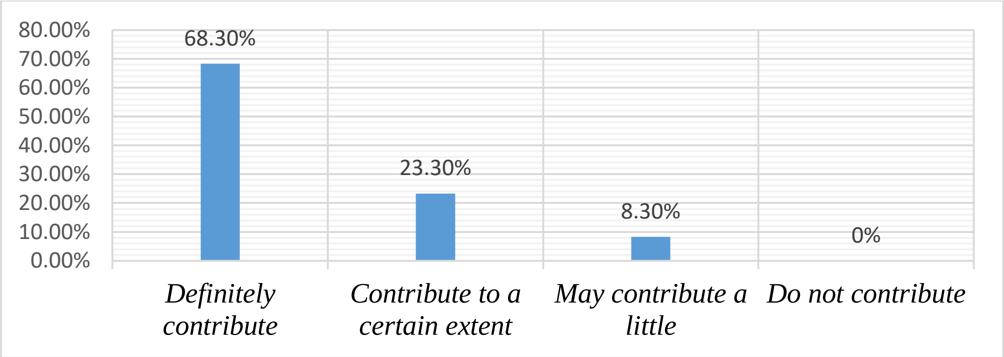

Figure 5.14. *The Contribution of Vegetated Building Elements to Energy Efficiency and Reducing Costs.*

The catalysts of the application

According to the evaluation of the participants, the following motivator factors affect the process of applying vegetated building elements: contribution to economic savings in the long-term, controlling climate change, the interest of the owner/ investor/ institution in society and environment, the support of governments for sustainable projects, and finally the level of awareness and interest of decision makers, such as; governmental authorities and environmental protection organizations. While the catalysts that strongly influence the application of vegetated building elements are; improvement of indoor air quality and reduction of the negative impacts of buildings, and providing energy efficiency and a sense of comfort for the occupants of buildings, protecting the environment and increasing biodiversity, as well as the awarded certificates for green buildings, (Figure 5.15).

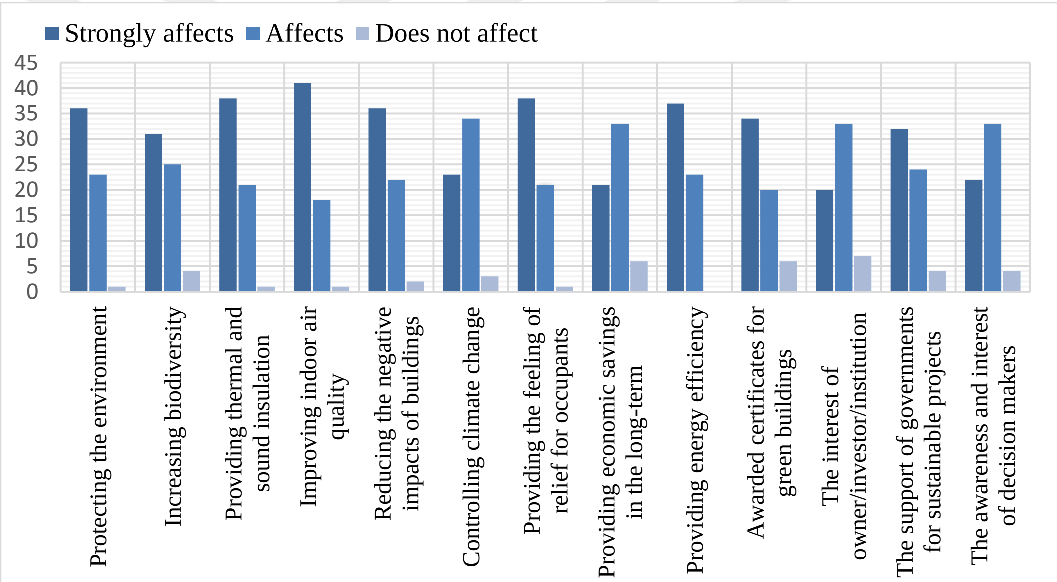

Figure 5.15. *The Effect of Several Catalysts on the Application of Vegetated Building Elements.*

The barriers of the application

The barriers that affect the application of vegetated building elements according to the participants are: difficult climatic conditions, lack of governmental tax incentives, frequent maintenance requirements, lack of specialized professionals, and lack of proper market. Moreover, the following barriers are thought to be strongly affecting the application process: lack of modern management skills, lack of awareness among stakeholders, high initial cost, lack of knowledge, lack of proper regulations or difficulty in legal procedures and, and finally, lack of demand by the user/client, as seen in Figure 5.16.

This result is consistent with the finding of the literature review in some main points, as the unique study, conducted by Tassicker et al., based on a survey regarding the application of green roofs, concluded that the lack of proper market and lack of demand by the user, as well as the lack of incentives from governmental and industrial bodies strongly affect the application and spreading of green roofs. It should be noted that one of the participants stated "I think there isn't enough demand or there isn't enough push" (Tassicker et al., 2016., p. 5). Furthermore, the author added that the initial cost of green roofs with the lack of knowledge of real benefits represents a major barrier and a significant concern for building owners and developers (Tassicker et al., 2016). Aupetit and Lundberg (2011) also agrees on the effect of these factors on the application process of green walls. Another point consistent with the study of Timur and Karaca (2013) is that the plants in green walls are less prone to pests, fungus, and diseases. The reason for this is the passage of air and being exposed to a sufficient amount of sun light. As a barrier factor, regarding the possibility of fires, studies have shown that there is not actually a certain fire risk linked with the green roofs. In fact, some of the green wall and roof systems are designed to provide fire resistance (FLL, 1995). Sam Hui stated that "there is evidence suggesting that green roofs can help slowing the spread of fire to and from the building through the roof" (Hui, 2011, p. 42).

On the other hand, there is a contradicting result of the questionnaire findings in comparison with literature reviews, regarding the effect of difficult climatic conditions on the application of vegetated building elements, as Sharp et al., (2008) conclude that green walls can be applied successfully in several climates. Additionally, Sadeghian mentioned that: "green wall can be built outside (green facade, living wall) or inside a building cover in variety country and under various weather" (Sadeghian, 2016, p. 50). Also Timur and Karaca have supported this view by stating: "green walls perform well in various climate environments. However, the selection of better species may adapt to the prevailing climatic condition" (Timur & Karaca, 2013, p. 592). Elliot (2008) mentioned that green roofs have the greatest potential in hot-dry climates.

Other studies pointed out the importance of choosing correct plants capable of withstanding drought and high temperature, and native plants that can grow and adapt to difficult climatic conditions for several years (Li & Yeung, 2014; Perry, 2010).

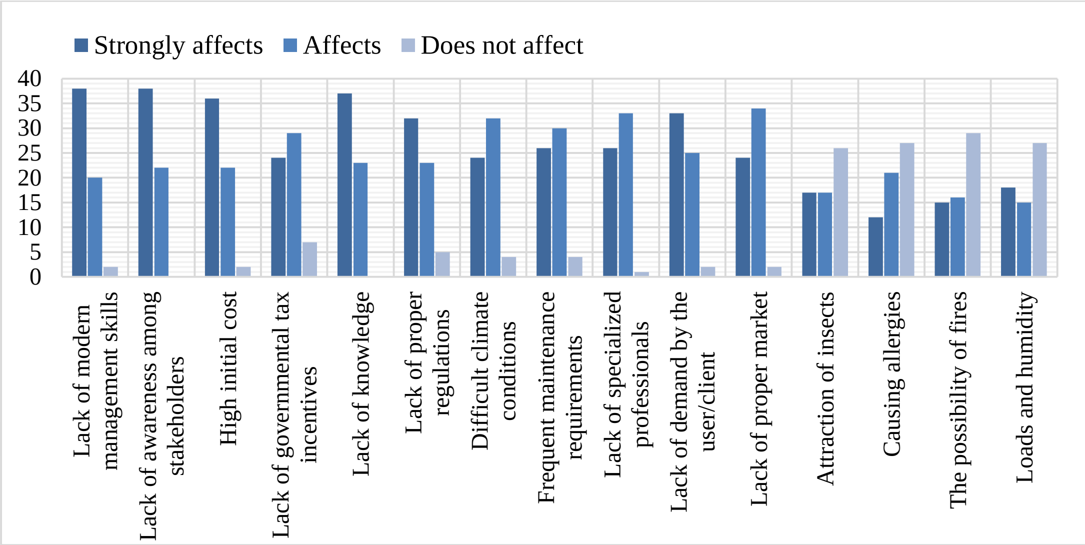

Figure 5.16. *The Effect of Several Barriers on the Application of Vegetated Building Elements.*

The participants position on the application and its vital need

More than two-thirds of the respondents strongly agree with the application of vegetated building elements. Nearly the same percentage believe that there is definitely a vital need for their application to achieve sustainability for future generations. Collected data confirm the perception of vegetated building elements as an integral part of future development, as shown in Figures 5.17 and 5.18. All studies agree that green walls, roofs, and interior gardens outperform traditional building elements in terms of achieving the fundamental elements of sustainability, from economic, social, and environmental perspectives (Tassicker et al., 2016). This type of new building technology represents an ideal solution for more developed cities (Loh, 2008).

Linking this finding with the previous ones, it seems that participants, in fact, have a very good knowledge of the importance of improving indoor air quality and wide spreading green spaces in urban environments. Aupetit et al., has mentioned that "architects and designers do not conceive a future without plant, especially a future without green walls" (Aupetit & Lundberg, 2011, p. 34). These positive results actually illustrates the desire of professionals and academics for change and development, to overcome the challenges, as well as to create future solutions for environmental and health issues in both buildings and cities.

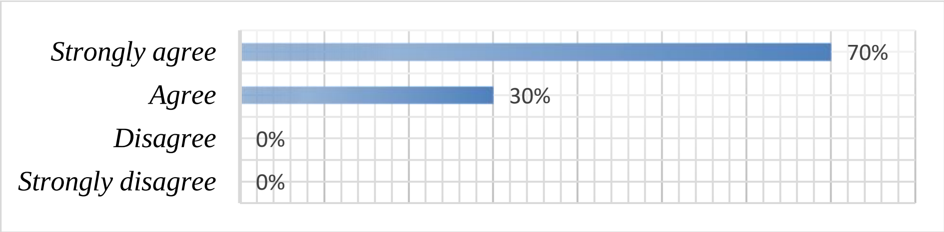

Figure 5.17. *The Responses Position on the Application of Vegetated Elements in Buildings.*

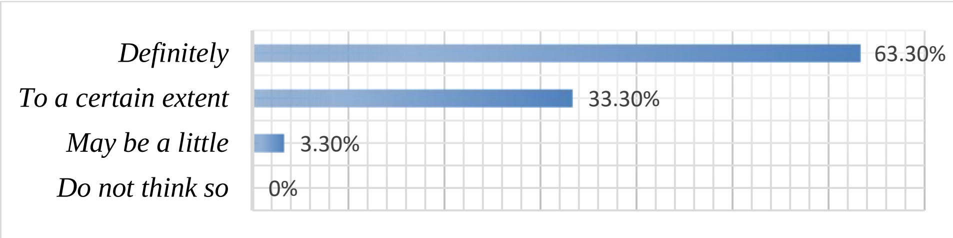

Figure 5.18. *The Vital Need for the Application of Vegetated Building Elements to Achieve Sustainability for Future Generation.*

Professions effect on future development

Regarding the effect of different professions on promoting the application of vegetated building elements in future development, participants believe that architects occupy the first place in terms of importance followed by designers, developers, investors, building owners, building users and contractors respectively, as seen in Figure 5.19. A similar study conducted by Wilkinson et al., based on a survey regarding the application of green roofs, which had a smaller scale, targeting stockholders in Sydney in 2012, found that for encouraging the widespread application of green roofs, a great deal of pressure lies on designers and architects, as to their opportunities for creating spaces containing plants in buildings (Wilkinson et al., 2015). However, this statement contradicted with another study by Tassicker et al., which was also conducted through a survey for professionals and academicians in Australia in 2016. It was stated that the responsibility for promoting the widespread application of green roofs lies on the client (Tassicker et al., 2016).

Thus, it can be assumed that the results of this research regarding this factor could be determinative among these two studies. The results of this study strongly support the study of Wilkinson et al., (2015) as it was found that the responsibility lies on architects and designers to convince and push the client towards the application of such projects. Anderson et al., stated that: “designers will need to do the right thing by including planting in their sustainable designs” (Anderson et al., 2004, p. 3). However, professions related to construction and development today are responsible for providing future strategies and plans to solve environmental, social and health issues. Moreover, the cooperation of professions would promote concept of sustainable buildings and create projects more that are environmentally-friendly.

Figure 5.19. *The Effect of Professions Related to Promoting the Application of Vegetated Building Elements on Future Development.*

Motivational factors for the future application

The participants thought that the most motivating factor for the application of vegetated building elements is the dissemination of related studies, which in turn represents knowledge increase and experience for interested. In addition to that, the results of these studies could lead to eliminating the barriers, concern, and significantly increasing innovation and development related to the application. Thus, the condensation of studies through local and international examples is a real opportunity for researchers and academics to achieve a comprehensive perception of the vegetated building elements, including economic aspects related to the application and maintenance, which is always considered relatively expensive. These studies would contribute to reducing the cost in the future. Secondly, they thought that the financial or moral support from effectual institutions has a significant role in motivating the spread of vegetated building elements. This support could be in the form of loans, discounts, or grants. This approach of support was implemented in several countries and was well received by investors, users. In addition, some sustainable building assessment tools, such as LEED, and BREEAM gives certain points for the application of green walls, roofs, and interior gardens, which in turn enable them of getting certification.

Undoubtedly, increasing awareness of environmental problems is also an important motivating factor for the application of vegetated building elements, which is consistent with previous studies that the solution for the environmental issues is the responsibility of everyone as a whole. However, a study conducted by Wilkinson et al., concluded that most of the environmental motivators for the application of sustainable projects are less important than the economic and social motivators as he mentioned that "practitioners focus on individual projects rather than city wide issues" (Wilkinson et al., 2015, p. 10). This may be a dangerous indicator of increasing environmental problems unless it is predicted and there were attempts to develop ideal solutions to eliminate them. Finally, responses pointed out to the importance of providing necessary materials in the local market and that having regulations of policies could contribute to the integration of more plants with the building elements, as in Figure 5.20.

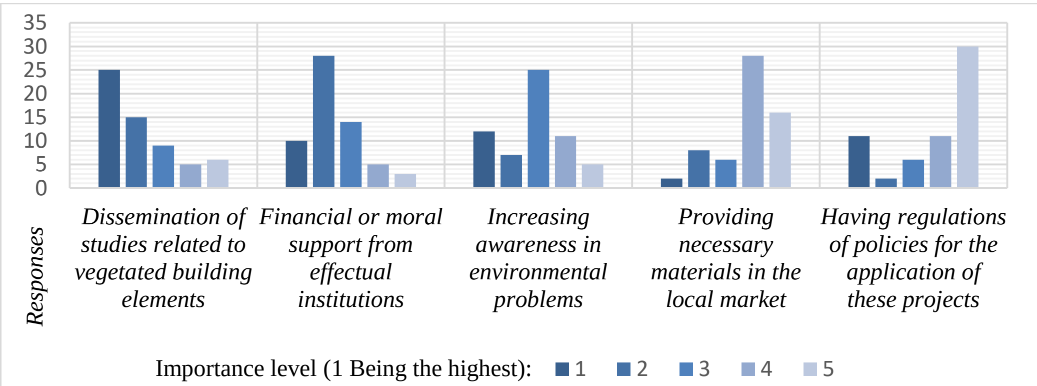

Figure 5.20. *The Significance of Motivational Factors for the Future Application of Vegetated Building Elements.*

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Together with the excessive use of energy, which led to higher spreading of pollutants in the air, the issue of climate change, and the increase in average global temperature, environmental concerns are becoming highly important to sustain a healthy life in urban areas. Human activities and the used materials and techniques in traditional buildings affect the quality of air negatively in cities. With the increase in population and the lack of green areas, this problem is growing rapidly. Therefore, today ideal solutions that ensure healthier buildings and urban areas should be search for. Perhaps the issue should be considered with a comprehensive view regarding the elimination of the sources of pollution and preserving good air quality without chemical components. As buildings are part of the environment, the environmental problems will certainly affect the residents of these buildings negatively. Thus, sustainable development and environment-friendly building techniques could help solve these issues. Certain developments in architecture could result in less energy demanding buildings. The integration of plants in building elements such as walls, roofs, and interior gardens will contribute to the improvement of air quality by the absorption of pollutants from air and production of oxygen. Plants also have a significant role in providing thermal comfort in buildings through cooling and regulating temperature by providing shading, absorbing solar radiation, and increasing the process of evaporation. Wider application of vegetated building elements would represent better results from environmental, social, and economic perspectives.

As to an overall evaluation of the research findings, there was a significant responsibility of academicians and professionals for spreading the application of vegetated building elements. There seemed to be a considerable amount of knowledge for the technical issues related to the application and a satisfactory level of awareness of the importance of architecture in achieving sustainability for future generations, although there still lied the need for higher training and upgrading skills in certain aspects of the issue. It is believed that there is a vital need to have solutions for the issue of excessive use of energy and the increase in environmental pollution. In addition to the need for the support and adoption of these projects by decision makers and authorities, to reach a wider application area, the consideration of other several factors are needed as well. Regarding the benefits of these systems, a higher level of awareness of the community will certainly lead to a more sustainable built environment.

Moreover, Aspects related to the application process show strong possibilities for the application of vegetated building elements on different building types and structures, which represents bigger opportunities for the ability of significantly increasing the application of buildings of high indoor air quality and less energy demanding. However, vegetated building elements should be considered as live and dynamic systems that are affected by man-made and natural factors. Therefore, the role of academicians and professionals is important in overcoming barriers for their application and providing improvements to fit the needs of all buildings and environments. The difference between the previous studies and the results of this thesis was not significant regarding the techniques of installation, catalysts and the high rated barriers, which are the lack of proper regulations, lack of demand by the user/client, and the importance of choosing the correct plant. Moreover, if the catalysts and barriers were developed, the application rates of vegetated building elements will be increased.

Regarding the countries in Mid-temperate climate, such as Turkey, plants could be adapted to climatic conditions. Thus, the ensure of the continuous of plants growth for a long period of time could be easily achieved. However, the aspects related to the application techniques and the building condition should not be neglected. Therefore, Turkey has a big opportunity for the spread of vegetated building elements application in future development. In the case of Libya, Malaysia, and Canada, their climatic conditions require comprehensive study during the design process for the suitable plant types according to their hard climatic conditions. Finally, it was seen that, the architects have the most fundamental role in developing such environment-friendly and healthy practices in architecture to build a sustainable future. To sum up, future provisions of environment-friendly buildings and healthy urban areas cannot be realized without the integration of vegetated building elements.

Recommendations for professionals and academics

- The correct plants should be selected; those that are able to tolerate dehydration and do not require continuous irrigation. Native plants and seeds may be the best as they capable of withstanding the local climate conditions.
- Plants vary in types, sizes, and characteristics. Therefore, they should be chosen according to the design goal, as there are types of plants contribute better to cooling and absorbing pollutants. Researchers should also create a comprehensive database of all types of plants with their nutrition and irrigation requirements.
- Measures should be followed for the maintenance procedure and to ensure safety on the site.
- Designers should select the proper system and installation method of vegetated building elements that fits the design and does not cause damage to the plants or structure. In addition to creating designs that contain harmony between both parts (live - inorganic).
- Responses have put the big responsibility of the execution, managing, and promoting the spread of the application of vegetated building elements on the architect. Thus, the importance of this issue should be emphasized through educational programs, especially in the faculties of architecture.
- Specialized professionals of architects, civil engineers, and contractors should be developed and trained regarding the application of vegetated building elements through the condensation of specialized events, such as courses, training programs, and conferences.
- Architects should persuade investors and users to integrate plants in the design of buildings.
- According to responses, interior gardens affect positively the architecture layout. Therefore, plants could be employed easily in the interior spaces, especially in hospitality and healthcare buildings as preferred by participants.

- Civil engineers must measure loads carefully when designing building structures that will contain vegetated building elements, including the expected weight of plants when growing.
- Environmental issues are the problem of this era. Therefore, several specializations related to these issues are trying hard to finding ideal solutions. For that reason, having strong relations and continuous cooperation between these specializations could lead to better results.
- Building market should be developed and provided all the materials required for the application of vegetated building elements. In addition to the local production of materials.
- It was found that the Internet is the easiest and best option for gaining knowledge about the application of vegetated building elements. Therefore, academics and professionals should condense studies and spread it widely as open access materials on the Internet.
- Future studies should be conducted to include other countries from different climatic zones, and target various institutions and professions.

Recommendations for decision makers

- Governmental, non-governmental, profitable, and non-profitable organizations should seek to increase awareness in the communities of the sources of pollutions and their negative effect on health. This may be done through advertisements and visual media.
- Governments should put obligatory laws and policies for the application of sustainable architecture including vegetated building elements.
- Governments must offer incentives and financial grants to promote the spread of vegetated building elements.
- Governments should have a significant role in spreading the application of vegetated building elements through facilitating legal procedures, incentives, and eliminating taxes, as the case in Canada, the USA, and Europe, which witnessed great popularity for this type of sustainable architecture through following this approach.
- Governments should plan to integrate governmental buildings with vegetated building elements.

- Developing and poor countries could conduct a comprehensive feasibility study to contribute to the solution of environmental issues in the form of financial loans to investors and users that could be repaid later.

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Appendix A

Table A1. *Investigations on Reducing Air Pollutants by Using Green Roofs and walls* (Charoenkit & Yiemwattana, 2016)

Type	**Method**	**Substrate depth**	**Climate and location**	**Plant species (type)**	**Carbon sequestration** (Kg cm $^{-2}$/year)
Green roofs	Measured from the above-, below-ground biomass and substrate.	6 cm	Temperate Michigan, US	4 sedum species	0.375
Green roofs	Calculated from the above-, below-ground biomass and substrate.	20.4 cm	Temperate Michigan, US	Mixed sedum species	2.15
				Mixed prairie species	2.60
				Mixed perennial plant species	30.12
Green roofs	Measured from the above-, below-ground biomass and substrate.	30 cm	Subtropical Chengdu, china	Vicaryi (perennial plant)	7.03-7.11
				Auriculata (flowering plant)	4.73-4.81
				Spicata (flowering plant)	4.77-4.85
Living walls	Modelling carbon flux of the entire system.	N/A	Mediterran ean	1. Zoysia matrella (grass)	0.98
				2.Sedum spurium (succulent plant)	0.14
				3.Salvia nemorosa (herbaceous plant)	0.95
				4. Rosmarinus officinalis (herbaceous plant)	0.99
				5.Geranium sanguineum (flowering plant	0.32
				6. Carex brunnea (herbaceous plant)	0.86
				7. Fatsia japonica (flowering plant)	0.41

Appendix B

Classification of Plants and the Average Annual Temperature for Different

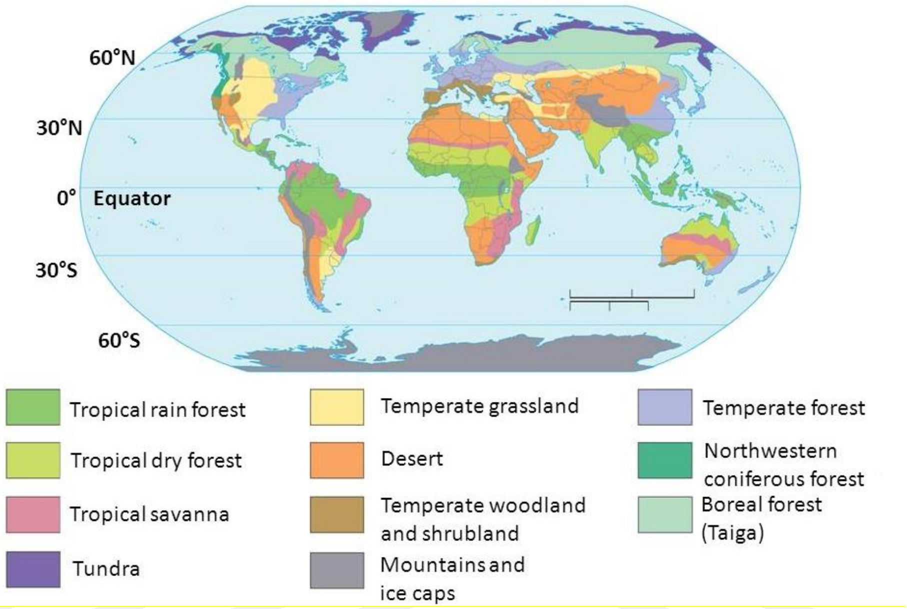


Figure B 1. *A Map Showing the Classification of Plants Appropriate for Numerous Zones* (Lambrechts, Wilkie, Rucevska, & Sen, 2009).

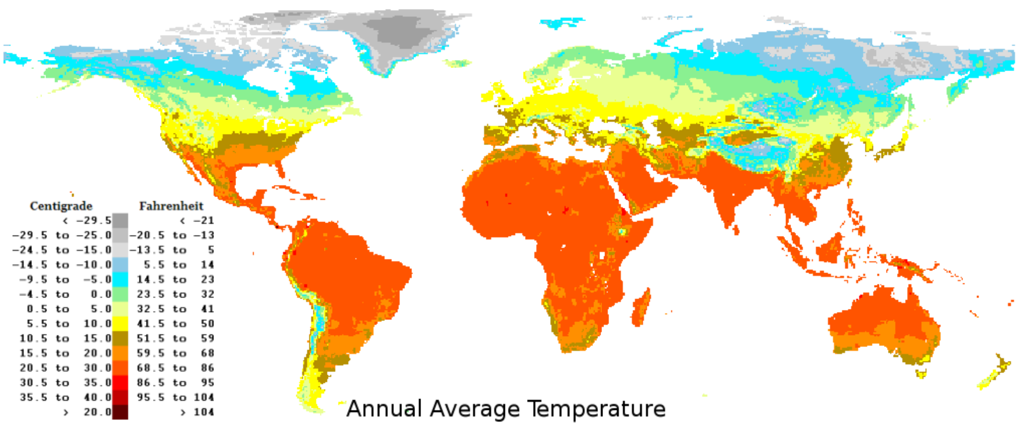


Figure B 2. *A Map Illustrating the Average Annual Temperature for Different Geographical Zones* (Lydolph, 1985).

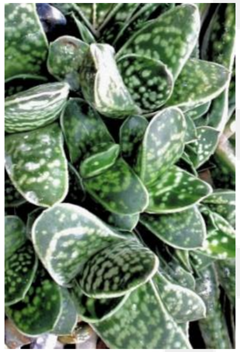
Appendix C

Table C1. *A List of Several Plants Able to Resist Drought for a Period of Time without Watering and their Original Habitat* (Liu et al., 2012).

Species	**The original habitat**	**height**			**Plant**		**Leaf**		**Leaf size**		
		Low	Medium	High	Creepin	Erection	Thin	Thick	Small	Medium	Large
Rhoeo spathaceo cv. Compacta	Cultivation		✓			✓	✓			✓	
Setcreasea purpurea Boom	Mexico		✓			✓	✓			✓	
Billbergia spp.	American		✓			✓	✓			✓	
Kalanchoe thyrsiflora	South Africa		✓			✓		✓			✓
Kalanchoe longiflora var. coccinea	South America		✓			✓		✓		✓	
Echeveria atropurpuream	Mexico		✓			✓		✓			✓
Neoregelia ‘Fireball’	South America		✓			✓	✓			✓	
Portulacaria afra	South Africa			✓		✓		✓	✓		
Pachyveria Pachyphytoides Walth	Mexico		✓			✓		✓		✓	
Portulacaria afra f. variegata	Cultivation			✓		✓		✓	✓		
Echeveria cv. Hanatsukiyo	Mexico	✓				✓		✓	✓		
Echeveria Chihuahuaensis Sedum Bitter	Mexico		✓			✓		✓		✓	
Echeveria pulidonis	Mexico			✓		✓		✓	✓		
Sedum pachyphyllum Rose	Mexico		✓			✓		✓		✓	
Kalanchoe hildebrandtii	Madagascar			✓		✓		✓		✓	
Euphorbia stenoclada	Madagascar			✓		✓		✓	✓		
Pedilanthus tithymaloides (L.) Poit	Cultivation			✓		✓	✓			✓	
Gasteria gracilis Baker	Africa	✓				✓		✓			
Kalanchoe milloti	Madagascar		✓			✓		✓		✓	
Kalanchoe	Madagascar			✓		✓		✓		✓	

Table C2. *A List of Several Plants Able to Resist Drought and Their Pictures* (Townshend & Duggie, 2007; Townshend & Duggie, 2007).

Name	**Figure of plant**	**Name**	**Figure of plant**
Rhoeo spathaceo cv.		Setcreasea purpurea	
Billbergia spp		Kalanchoe thyrsiflora	
Kalanchoe longiflora var		Echeveria atropurpuream	
Portulacaria afra		Neoregelia (Fireball)	
Portulacaria afra f. (Variegata)		Chihuahuaensis sedum	

Kalanchoe fedtschenkoi	Gasteria	Euphorbia stenoclada	Sedum pachyphyllum	Echeveria
				
Pachyveria	Kalanchoe milloti	Tithymaloides	Kalanchoe hildebrandtii	Echeveria pulidonis
				

Appendix D

Suitable Plants and Their Characteristics for Vegetated Building Elements

Table D1. *Plant Selection for (Intensive) Green Roof System* (Townshend & Duggie, 2007).

Plant Name	**Size MEDIUM**	**Size SMALL**	**Wind Tolerant**	**Pollution Tolerant**	**Evergreen**	**Deciduous**	**Fast Growing**	**Medium Growing**	**Slow Growing**	**Conspicuous Flowers**	**Interesting Foliage**
Areca catechu		✓	H	M	✓			✓			✓
Bismarckia nobilis	✓		H	M	✓			✓			✓
Cocos nucifera	✓		H	M	✓			✓			✓
Cycas revoluta		✓	H	M	✓				✓		✓
Hyophorbe lagenicaulis		✓	H	M	✓			✓			✓
Hyophorbe verschaffeltii	✓		H	M	✓			✓			✓
Neodypsis decaryi		✓	H	M	✓			✓			✓
Pandanus veitchii		✓	H	M	✓				✓		✓
Phoenix dactylifera	✓		H	M	✓				✓		✓
Phoenix hanceana	✓		H	M	✓				✓		✓
Phoenix sylvestris	✓		H	M	✓				✓		✓
Phoenix roebelenii		✓	H	H	✓			✓			✓
Livistona chinensis	✓		H	H	✓			✓			✓
Wodyetia bifurcata		✓	H	M	✓				✓		✓
Washingtonia robusta			H	M	✓				✓		✓
Araucaria heterophylla			H	M	✓				✓		✓
Callistemon viminalis			M	M	✓				✓	✓	
Cassia surattensis			M	M	✓		✓			✓	
Cinnamomum burmannii			M	M	✓			✓			
Eleaocarpus hainanensis			M	L	✓				✓		
Ficus benjamina			H	H	✓			✓			
Ficus microcarpa ‘Golden Leaf			H	H	✓			✓			
Garcinia spicata			H	H	✓				✓		
Hibiscus tiliaceus			H	H	✓		✓			✓	
Juniperus chinenisis cv.Kaizuca			H	M	✓				✓		

Koelreuteria bipinnata			M	L		✓		✓		✓	
Lagerstroemia speciosa			M	M		✓	✓			✓	
Magnolia grandiflora			M	L	✓				✓		
Michelia x alba			M	M	✓			✓			
Michelia champaca			M	L	✓			✓			
Nageia nagi (syn. Podocarpus nagi)			M	L	✓				✓		✓
Pongamia pinnata			H	M	✓			✓		✓	
Podocarpus macrophyllus			M	L	✓				✓		
Schefflera actinophylla			M	M	✓		✓				

H: High. M: Medium. L: Low.

Table D 2. *Plant Selection for (Extensive) Green Roof System* (Townshend & Duggie, 2007).

Plant Name	**Common Name**	**Minimum Soil Depth (cm)**	**Maintenance (H / M / L)**	**Wind Tolerant**	**Pollution Tolerant**	**Growth Rate (F / M / S)**	**Conspicuous Flowers**	**Interesting Foliage**
Zephyranthes~candida	Autumn zephyr-lily	8	L	H	M	F	✓	
Zephyranthes grandiflora	Rose-pink zephyr-lily	8	L	H	M	F	✓	
Bryophyllum ‘Crenatodaigremontianum’	Dancing butterfly	8	L	H	H	F		✓
Bryophylum fedtschenkoi	Lavender scallop	8	L	H	H	F		✓
Furcraea foetida ‘Mediopicta’	Mauritius hemp	8	L	H	M	M		✓
Kalanchoe tomentosa	Panda plant	8	L	H	H	M	✓	
Liriope muscari	Variegated lily turf	8	L	H	M	F		
Portulaca oleracea	Purslane	8	L	H	M	F	✓	
Portulaca pilosa	Kiss-me-Quick	8	L	H	M	F	✓	
Rhipsalis mesembryanthemoides	Clumpy mistletoe Cactus	8	L	H	M	F		✓
Sansevieria trifasciata ‘Golden Hahnii’	Golden birdsnest	8	L	H	H	M		✓
Sansevieria trifasciata ‘Hahnii’	Bird Nest sansevieria	8	L	H	H	M		✓
Sedum acre	Biting Stonecrop	8	L	H	H	F		✓
Sedum lineare	Variegated stonecrop	8	L	H	H	F		
Sedum lineare ‘Variegatum’	Variegated sedum	8	L	H	H	F		✓
Sedum mexicanum	Mexicum sedum	8	L	H	H	F		✓
Sedum nussbaumerianum	Coppertone sedum	8	L	H	H	F		✓
Sedum sarmentosum	Stringy stonecrop	8	L	H	H	F		✓
Sedum sexangulare	Tasteless stonecrop	8	L	H	H	F		✓
Sesuvium portulacastum	Sea purslane	8	L	H	H	F		
Tradescantia pallida‘Purpurea’ New:Setcreasea purpurea	Purple heart	8	L	H	H	F		

Tulbaghia violacea	Wild garlic	8	L	H	H	F		
Zephyranthes rosea	Fairy lily	8	L	H	M	F	✓	
Alternanthera ficoidea ‘White Carpet’	Alternanthera 'White Carpet'	8	L	M	M	F		✓
Commelina diffusa	Diffuse dayflower	8	L	M	M	F		
Murdannia nudiflora	Naked Flowered Murdannia	8	L	M	M	F		
Murdannia vaginata	Sheathed murdannia	8	L	M	M	F		✓
Portulaca grandiflora	Ross-moss	8	L	M	M	F	✓	
Arachis duranensis	Groundnut	10	L	H	H	F	✓	
Arachis pintoi	Amarillo	10	L	H	H	F	✓	
Axonopus compressus	Carpet Grass	10	L	H	H	F		
Stenotaphrum dimidiatum	Stenotaphrums	10	L	H	H	F		✓
Wedelia chinensis	Wedelia	10	L	H	H	F	✓	
Wedelia trilobata	Wedelia	10	L	H	H	F	✓	
Scutellaria indica	Skullcap	10	L	H	M	M		
Melastoma dodecandrum	Stamened melastoma	10	L	M	M	M		
Vitex rotundifolia	Beach vitex	15	L	H	H	F		
Crinum asiaticum var.	Chinese crinum	15	L	H	M	M	✓	
Hymenocallis littoralis	Spider lily	15	L	H	H	F	✓	
Osbeckia chinensis	Chinese osbeckia	15	L	H	M	M		
Sansevieria trifasciata	Spear sansevieria	15	L	H	H	M		✓
Alternanthera bettzickiana	Calico-plant	15	L	M	M	F		✓
Cyathula prostrate ‘Blood-red Leaves’	Blood-red leaves	15	L	M	M	F		
Lantana sellowiana	Lantana	15	L	M	H		✓	
Nephrolepis exaltata	Sword-fern	15	L	M	M	M		✓
Ophiopogon jaburan	Jaburan lily-turf	15	L	M	M	F		
Ophiopogon japonicus	Blue grass	15	L	M	M	F		
Asparagus densiflorus cv.	Springer asparagus	20	L	H	H	F		
Baeckea frutescens	Dwarf mountain pine	20	L	H	H	F		✓
Callisia repens	Creeping basketplant	8	M	M	M	F		✓
Plectranthus verticillatus	Swedish ivy	8	M	M	M	F		✓
Rhoeo discolor	Oyster plant	10	M	M	M	F		✓
Rhoeo discolor ‘Compacta’	Dwarf oyster plant	10	M	M	M	F		
Cuphea hyssopifolia	False heather	15	M	M	M	F	✓	
Iris tectorum	Crested iris	15	M	M	M	M	✓	
Liriope spicata	Lily turf	15	M	M	M	F		
Epipremnum aureum	Ivy-arum	15	M	L	M	F		
Aerve songuinolenta	Songuinea	20	M	M	M	F		✓

L: Low. M: Medium. H: High. F: Fast. M: Medium.

Table D 3. *Plant Selection for Green Wall Systems* (Green-screen, 2016).

	Usage		**Growth Habit**					**Cycle**			**Light**		
Plant Common Name	Wall mounted	Freestanding	Twining	Leaf Stem	Scrambler	Adhesive	Root Climber	Deciduous	Evergreen	Semi Evergreen	Full Sun	Partial Shade	Full Shade
Kiwi Vine	✓	✓	✓					✓			✓		
Evergreen Clematis	✓	✓	✓						✓			✓	
Pink Evergreen Clematis	✓	✓	✓						✓			✓	
Chauga Wild Hydrangea Vine		✓	✓					✓				✓	
Swamp Jessamine	✓	✓	✓						✓	✓	✓	✓	
Carolina Jessamine	✓	✓	✓						✓	✓	✓	✓	
Double Shot Jessamine	✓	✓	✓						✓	✓	✓	✓	
Cathedral Gem Sausage Vine	✓	✓	✓						✓	✓	✓	✓	
Silvervein Creeper		✓				✓		✓			✓	✓	
Asian Jasmine	✓	✓	✓						✓		✓	✓	
Angyo Asian Jasmine	✓	✓	✓						✓		✓	✓	
First Snow Asian Jasmine	✓	✓	✓						✓		✓	✓	
Ogon Nishiki Asian Jasmine	✓	✓	✓						✓		✓	✓	
Madison Jasmine	✓	✓	✓						✓		✓	✓	✓
Cabernet Sauvignon Grape	✓	✓		✓				✓			✓		
Chardonnay Grape	✓	✓		✓				✓			✓		
Flame Seedless Grape	✓	✓		✓				✓			✓		
Merlot Grape	✓	✓		✓				✓			✓		
Pinot Noir Grape	✓	✓		✓				✓			✓		
Ruby Seedless Grape	✓	✓		✓				✓			✓		
Thompson Seedless Grape	✓	✓		✓				✓			✓		
Zinfandel Grape	✓	✓		✓				✓			✓		
Vincent Kiwi Vine	✓	✓		✓				✓	✓		✓		
Coral Vine	✓	✓			✓			✓	✓		✓	✓	
Pink Jasmine	✓	✓			✓				✓		✓		
Varieties	✓	✓		✓				✓	✓		✓		
Butterfly Vine	✓	✓		✓					✓		✓	✓	
Star Jasmine	✓	✓		✓					✓		✓	✓	✓
Delta Dawn Bougainvillea	✓	✓			✓				✓		✓		
Lavender Trumpet Vine		✓		✓					✓		✓	✓	
Scarlet Trumpet Vine		✓		✓					✓		✓	✓	
Creeping Fig		✓				✓			✓		✓	✓	
Blue Dawn Morning Glory	✓	✓	✓						✓		✓	✓	
Arabian Jasmine	✓	✓	✓						✓		✓	✓	
Yellow Trumpet Vine		✓		✓					✓		✓	✓	

White Bower Vine	✓	✓	✓						✓		✓	✓	
Charisma Bower Vine	✓	✓	✓						✓		✓	✓	
Pink Bower Vine	✓	✓	✓						✓		✓	✓	
Varieties	✓	✓			✓				✓		✓		
Royal Trumpet Vine		✓		✓					✓		✓	✓	
Giant Burmese Honeysuckle		✓	✓						✓		✓		
Himrod Grape	✓	✓		✓				✓			✓		
Venus Seedless Black Grape	✓	✓		✓				✓			✓		
Traminette White Wine Grape	✓	✓		✓				✓			✓		
White Japanese Wisteria		✓	✓					✓			✓		
Pink Japanese Wisteria		✓	✓					✓			✓		
Texas Purple Japanese Wisteria		✓	✓					✓			✓		
Amethyst Falls American Wisteria		✓	✓					✓			✓		
Summer Cascade Wisteria		✓	✓					✓			✓		
Chinese Wisteria		✓	✓					✓			✓	✓	
Ritak Sausage Vine	✓	✓	✓						✓			✓	✓
Fiveleaf Akebia	✓	✓	✓					✓		✓	✓	✓	✓
Shirobana Akebia	✓	✓	✓					✓		✓	✓	✓	✓
English Ivy		✓					✓		✓			✓	✓
Thorndale English Ivy		✓					✓		✓			✓	✓
Climbing Hydrangea	✓	✓					✓	✓				✓	✓
Triple Crown Blackberry		✓			✓			✓			✓	✓	
Black Satin Blackberry		✓			✓			✓			✓	✓	
Arapaho Blackberry		✓			✓			✓			✓	✓	
Crystal Hop	✓	✓	✓					✓			✓	✓	
Mirranda Climbing Hydrangea		✓					✓	✓	✓	✓		✓	✓
Hall's Japanese Honeysuckle	✓	✓	✓					✓	✓	✓	✓	✓	
Peaches and Cream Honeysuckle	✓	✓	✓					✓			✓	✓	
Scentsation Honeysuckle	✓	✓	✓					✓			✓	✓	
Sweet Tea Honeysuckle	✓	✓	✓					✓			✓	✓	
Kintzley's Ghost Honeysuckle	✓	✓	✓					✓	✓	✓	✓	✓	
John Clayton Honeysuckle	✓	✓	✓					✓	✓	✓	✓	✓	
Trumpet Honeysuckle	✓	✓	✓					✓	✓	✓	✓	✓	
Coral Honeysuckle	✓	✓	✓					✓		✓	✓	✓	
Goldflame Honeysuckle	✓	✓	✓					✓		✓	✓	✓	
Harlequin Honeysuckle	✓	✓	✓					✓		✓	✓	✓	
Mandarin Honeysuckle	✓	✓	✓					✓			✓	✓	
Virginia Creeper		✓				✓		✓			✓	✓	✓
Star Showers Virginia Creeper		✓				✓		✓			✓	✓	✓

Green Showers Boston Ivy		✓				✓		✓			✓	✓	✓
Boston Ivy		✓				✓		✓			✓	✓	✓
Climbing Rose	✓	✓			✓			✓			✓		
Canby Red Raspberry		✓			✓			✓			✓		
Heritage Raspberry		✓			✓			✓			✓		
Indian Summer Raspberry		✓			✓			✓			✓		
Catawba Grape	✓	✓		✓				✓			✓		

Appendix E

A Questionnaire of the Level of Awareness and the Possibility of Applying Vegetated Building Elements

This questionnaire invited professionals and academics to participate in a research study conducted by a graduate student at the faculty of architecture at Cankaya University in Turkey, to obtain a master’s degree in Interior Architecture.

Definition:

Vegetated building elements are created by using plants at various building parts, such as roofs, exterior and interior walls and interior spaces (as inner gardens), which significantly contribute to the development of environment-friendly buildings and urban communities, as they help to reduce the negative impacts of buildings on the environment.

This study aims to obtain the views of experienced professionals in the fields of architecture and engineering, regarding the level of importance of the application of vegetated building elements and to obtain data about the possible catalysts and barriers for their applications in different climatic zones.

This questionnaire should take about 10 minutes. All the information provided by the participants will be kept confidential and will be used only for academic purposes.

The agreement of participation:

I understand the above descriptive content and I agree on participating in this research study:

○ Yes, I agree ○ No, I do not agree

A. Personal Information:

1. What country are you from?

○ Turkey ○ Libya ○ Malaysia ○ Canada

2. Field of expertise:

○ Architecture ○ Civil Engineering ○ Urban Design ○ Landscape Design

○ Planning Engineering ○ Investment ○ Agronomy

3. Years of experience in your field:

○ Less than 5 years ○ 5-10 years ○ 11-15 years ○ More than 15 years

4. Number of building projects participated in:

○ Less than 5 Projects ○ 5-10 Projects ○ 11-20 Projects ○ More than 20 Projects

5. Do you have any knowledge on vegetated building elements such as; green walls, roofs, and interior gardens?

○ Yes ○ No

6. If you have any knowledge on vegetated building elements, from where did you obtain it? (check all that apply)

○ Conferences ○ Colleagues ○ Internet ○ Field Experience

○ Specialized Courses ○ Commercials (Advertisements)

7. Have you ever participated in projects involving the construction or design of vegetated building elements?

○ Yes ○ No

B. General Perception of Vegetated Building Elements:

8. Do you have knowledge on the function and benefits of plants**?**

○ I have never heard of it ○ I know a little ○ Yes, I have sufficient knowledge ○ I have comprehensive knowledge

9. From your experience, are vegetated elements applicable on buildings with different construction methods**?** If not, please check the applicable structure types.

- ○ Concrete Structures
- ○ Steel Structures
- ○ Timber Frame Structures

10. Please sort the below-given building types considering the significance of the application of vegetated building elements (From; 1: the most important, to; 6: the least important).

- ..... Residential Buildings
- ..... Health Care Buildings
- ..... Institutional Buildings
- ..... Commercial Buildings
- ..... Educational Buildings (Schools, Colleges)
- ..... Hospitality Buildings (Hotels, Resorts, etc.)

11. Do interior vegetated walls and interior gardens affect the architectural layout of the building**?**

- ○ Affect positively
- ○ Do not affect
- ○ Affect negatively

12. What is the possibility of applying vegetated elements to historical buildings?

- ○ Definitely possible
- ○ Possible to a certain extent
- ○ May not be possible
- ○ Definitely impossible

13. What is the possibility of designing structures capable of withstanding large loads of green roofs?

- ○ Definitely possible
- ○ Possible to a certain extent
- ○ May not be possible
- ○ Definitely impossible

14. Please sort the below-given professionals considering their significance in managing and implementing vegetated building elements in projects (From; 1: the most important, to; 8: the least important).

- ..... Architect
- ..... Financial Expert
- ..... Urban planner
- ..... Civil engineer
- ..... Project owner
- ..... Landscape Designer
- ..... Environmental Engineer
- ..... Information Technologist

15. Do you think periodic checks for the maintenance of vegetated building elements are important?

- ○ Yes, definitely
- ○ Yes, to a certain extent
- ○ May be a little
- ○ No, I do not think so

16. Do you think that vegetated building elements contribute to energy efficiency and reduce costs?

- O Yes, definitely
- O Yes, to a certain extent
- O May be a little
- O No, I do not think so

17. Please evaluate each catalyst regarding their level to affect the application of vegetated building elements (Please check the appropriate box for each factor).

	Catalysts	**Strongly affects**	**Affects**	**Does not affect**
1	Protecting the environment	O	O	O
2	Increasing biodiversity	O	O	O
3	Providing thermal and sound insulation for buildings	O	O	O
4	Improving indoor air quality	O	O	O
5	Reducing the negative impacts of buildings	O	O	O
6	Controlling climate change	O	O	O
7	Providing the feeling of relief for buildings occupants	O	O	O
8	Providing economic savings in the long-term	O	O	O
9	Providing energy efficiency	O	O	O
10	Awarded certificates for green buildings	O	O	O
11	The interest of owner/investor/institution in the society and environment	O	O	O
12	The support of governments for sustainable projects	O	O	O
13	The awareness and interest of decision makers, such as; governmental authorities and environmental protection organizations	O	O	O

Other factors:

1	....	O	O	O
2	....	O	O	O

18. Please evaluate each barrier regarding their level to affect the application of vegetated building elements (Please check the appropriate box for each factor).

	Barriers	**Strongly affects**	**Affects**	**Does not affect**
1	Lack of modern management skills	O	O	O
2	Lack of awareness among stakeholders	O	O	O
3	High initial cost	O	O	O
4	Lack of governmental tax incentives	O	O	O
5	Lack of knowledge	O	O	O
6	Lack of proper regulations or difficulty in legal procedures	O	O	O
7	Difficult climate conditions	O	O	O
8	Frequent maintenance requirements	O	O	O
9	Lack of specialized professionals	O	O	O
10	Lack of demand by the user/client	O	O	O
11	Lack of proper market	O	O	O
12	Attraction of insects	O	O	O
13	Causing allergies	O	O	O
14	The possibility of fires	O	O	O
15	Loads and humidity	O	O	O

Other factors:

1	....	O	O	O
2	....	O	O	O

C. Future Perception of Vegetated Building Elements:

19. What is your stand on the application of vegetated elements in buildings?

O I strongly agree O I agree O I disagree O I strongly disagree

20. Please sort the below-given factors of motivators for the future application of vegetated building elements, regarding their significance (From; 1: the most important, to; 5: the least important).

..... Dissemination of studies related to vegetated building elements
..... Financial or moral support from effectual institutions
..... Increasing awareness in environmental problems
..... Providing necessary materials in the local market
..... Having regulations of policies for the application of these projects

21. Please sort the below-given as to their significance in promoting the use of vegetated building elements (From; 1: the most important, to; 7: the least important).

.... Buildings' owner .... Investor .... Designer .... Building user
.... Developer .... Architect .... Contractor

22. Do you think that there is a vital need for the application of vegetated building elements to achieve sustainability for future generations?

O Yes, definitely O Yes, to a certain extent O May be a little O No, I do not think so