ROLE OF ROOF GARDEN

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1.0 Introduction

With international focus on sustainable development, interest in the role of open space in the urban environment has increased in recent decades (Gehl and Gemzoe, 2001; Hollis and Fulton, 2002). Policies for creating and preserving open space are increasingly implemented at a variety of urban densities and spatial scales. Many cities across the world have created green networks, green belts and programs to protect open space and restore connections to nature (Pendall et al., 2002).

Many cities across Europe (especially in Germany, France, Austria, Norway and Switzerland) and Asia have started to green the roofs of buildings. By 1996, one in ten flat roofs in German cities was greened while 70% of flat roofed inner city buildings in Swiss cities are reported to have roof gardens (Peck et al., 1999). In Asia, roof gardens are assiduously promoted in Japan, Hong Kong and Singapore. In Singapore, rooftop greening has gained the support of the government who will take the lead in implementing skydeck greenery in public housing estates and public buildings. The Tokyo government has passed a decree in April 2000 requiring all new buildings with a floor area of 1000m2 or larger to plant trees (namely, conifers and cedars) on rooftops (Environment Preservation Bureau Tokyo Metropolitan City, 1999).

Much has been said elsewhere about open space contributions to urban quality of life. Research across different disciplines has shown that greenery directly benefits the urban environment and Researchers have drawn attention to the human benefits. In particular, the work of Ulrich (1984) is widely cited as illustrating the restorative health benefits that window view greenery can have on patient recovery. In Knopf's (1987) analysis, there are four broad dimensions on how greenery affects urban living: nature as restorer, as competence builder, as symbol and as diversion. What is of interest to us, however, is the familiar argument which states that trees and vegetation may improve urban climate by reducing carbon dioxide and cooling the heat island (Dwyer et al., 1992). Green roofs constitute an area where photosynthesis would occur signifying that it consumes carbon. Hence, in large numbers, green roofs have the capacity to reduce carbon-based air pollutants and consequently help in carbon management.

While research on carbon management of urban parks exists, much less attention is being paid to the small-scale green areas that are close to where people live and work. This paper takes a closer look at one such area, the roof gardens, its usage and potential, through a case study of its application and development in Tehran, the capital city of Iran. Our intention is to contribute to the evolving theoretical and empirical discussions on this subject as we seek to understand the role of green spaces in air pollution control particularly in carbon management. This paper also seeks to ascertain the feasibility and sustainability of green roofs in water-thirsty, smog-covered Iran and putting forth recommendations regarding appropriate practices to be used in future planning of the city.

2.0 Literature Review

This chapter is primarily concerned in providing the necessary background for understanding the purpose of the research. The goal is to equip the reader with the knowledge to understand the concepts presented in the ensuing passages.

2.1 Air Pollution and the Tehran Urban Setting

One of the greatest challenges for human society today is air pollution, a phenomenon that refers to the addition of harmful substances to the atmosphere consequently damaging the environment and posing a threat to human health. Air pollution can be as local as inside a home or as widespread as to affect an entire continent. Aside from causing breathing problems and cancer, air pollutants also return to Earth in the form of acid rain and snow that have been shown to induce corrosion to buildings and statues, increase the salinity of lakes and streams and damage crops and foliage. Because of the burning of fossil fuels, the clearing of forests, and other such practices, the amount of CO_2 in the atmosphere has been increasing since the Industrial Revolution. Atmospheric concentrations have risen from an estimated 260 to 379 ppm[3]. This increase accounts for only half of the estimated amount of carbon dioxide poured into the atmosphere. The other 50 percent has probably been taken up by and stored in the oceans (Nowak and Crane, 2002). This increasing CO2 level has mainly been caused by emissions from the burning of fossil fuels such as coal, gasoline, and petroleum. Anthropogenic fossil fuel burning alone has produced approximately three-quarters of the increase in CO2 over the past 20 years (Pearson and Palmer, 2000) and emissions continue to increase (IPCC, 2007). Unless measures are taken to mitigate the accumulation of atmospheric CO2, these increases might pose a serious threat to ecological and socio-economic systems (Karl et al., 1997).

Tehran or Teheran is the capital and largest city of the Islamic Republic of Iran having an area of about 600 sq km. It is the country's economic, administrative and cultural centre as well as it industrial and transportation hub. Most of Tehran\s urban commercial and government buildings are concentrated in the city centre with residential areas at the periphery. As with many urban cities, Tehran is currently experiencing a chronic air pollution problem with over 4,000-5000 Iranians dying of air pollution related problems annually. Estimates have placed annual production of air pollutants at 1.5 million tons with carbon monoxide and carbon dioxide from car exhaust having the largest percentage. Cars spewing black smoke and leaking engines are a familiar sight in the city due to the approximately 75% of Tehran's 2 million vehicles being over 20 years old. These vehicles, which were produced by the Iran Khodro company in pre-Khomeini period, are characterized by low fuel efficiency, absence of catalytic converters and ability to process lead-free gasoline. (Behrooz and Karampour, 2008)

In December 1999, air pollution reached critical levels and the whole city was engulfed in high concentrations of carbon monoxide and other pollutants for several weeks. As a result of the smog, authorities were forced to cancel classes and declare a moratorium on the use of vehicles for several days in the city centre. Pollution was so severe that people could not go out of their residences without wearing gas masks or wetted handkerchiefs especially in the city centre (Aghayan, 2007).

Further aggravating Tehran's air pollution is its geographic position. Tehran is situated immediately downhill of the Alborz Mountain ranges making it difficult for the regional diffusion of air pollutants especially when air currents are not strong enough to blow the pollution away causing air pollutants to be entrapped. The city is also situated in high altitudes at 3,300-5,000 feet above sea level making combustion a more tedious process and inefficient. Furthermore, much of Tehran's greenery, specially the large swaths of orchards in the north, had long been sequestered for urban development thereby restricting the city's lungs. All of these factors have combined to make Tehran one of the most polluted cities in the world ranking with Mexico City, Beijing and Bangkok (Behrooz and Karampoor, 2008).

2.2 Plants and Carbon Sequestration

Increasing concern about climate change and rapid urbanization has recently generated studies about the effects of urban forests on the reduction of atmospheric CO2 (Abdollahi et al., 2000). Cities, or urban ecosystems, are important nodes of human activity, where in 2000 more than 47% of the world's population lived and 10% of these lived in megacities of 10 million or more people. By 2025 it is projected to be nearly two thirds (UN, 2006). Iran is (40.4% urban) is just beginning its shift, and will undergo rapid urbanization over the next several decades (McDonald, 2008). Cities consume increased amounts of energy, relative to other ecosystems and emit much of the world's CO2 as urbanization and industrialization keep pace with economic development (Guan and Chen, 2003). For example, global primary energy consumption by urban industrial sectors grew at a rate of 0.9% annually between 1995 and 2001, while energy consumption by non-urban agricultural sectors decreased at a rate of _2.4% during this time period (IPCC, 2005). Urban forests and green roofs have been reported to sequester atmospheric CO2 through growth and other functions such as shading buildings and thereby affecting cooling and heating, and storing CO2 in soils (Nowak and Crane, 2002; Pataki et al., 2006). Thus urban forests and green roofs, should contribute to mitigating the increasing levels of atmospheric CO2 (He and Ning, 2002; Nowak and Crane, 2002). More recently urban forests and green roofs are being used as a carbon offset strategy by several cities ((Jo, 2002; Hefty et al., 2007).

Carbon consumption of trees and plants involves the process of photosynthesis wherein carbon dioxide enters leaves through the stomata and is converted into organic compounds especially sugars with sunlight as its energy source. A simplified diagram is shown in Figure 1:

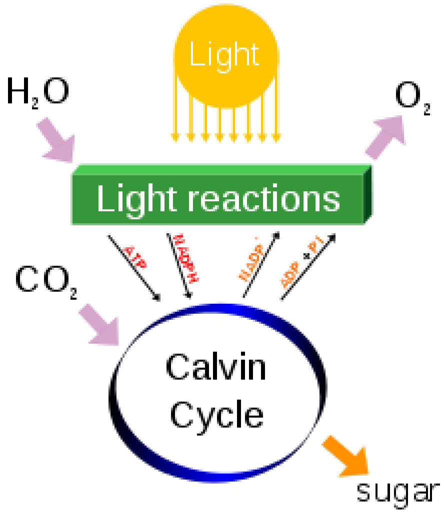

Figure 1: Photosynthesis (Jones, 2008)

Aside from photosynthesis, trees and plants remove carbon dioxide and other air pollutants by diffusing into intercellular spaces and absorption by water films to form acids. Leaves also intercept airborne pollutants in its surface area. Some of them are absorbed and integrated into the plant structure and the remainder washed off by rain or dropped to the ground when the intercepting leaf or twig falls.

2.3 Benefits of Green Roofs

Green roofs are an important technology and planning tool that can be used to help urban centres respond to climate change and improve urban environmental quality. Also referred to as living roofs or roof gardens, green roofs are roofs and podiums with vegetation growing in a specifically designed substrate. They have multiple demonstrated environmental benefits at a variety of scales. Benefits for individual buildings include increased roof life (Kosareo and Ries, 2007), insulating properties that lead to greater energy efficiency through reduced summer cooling and winter heating costs(Sailor, 2008) and attenuation of inside and outside noise levels(Van Renterghem and Botteldooren,2009). Green roofs can improve the local environment by providing biodiversity habitat (Brenneisen, 2006), reducing storm water flows (Carter and Jackson, 2007) and improving the quality of roof runoff water (Berndtsson et al., 2006). Unlike other water sensitive urban design measures they do not require additional space as they are already part of the building footprint.

On a city-wide scale green roofs can mitigate the urban heat island effect (UHI) through cooling due to increased evapotranspiration thus reducing energy use and carbon dioxide emissions (Skinner, 2006; Alexandri and Jones, 2008). They can also sequester carbon (Getter et al., 2009).

2.4 Applicability Issues for Tehran

Two types of green roofs are widely recognised; intensive and extensive. Intensive green roofs can support complex vegetation communities including groundcovers, small trees and shrubs in substrate depths greater than 20cm.They are often designed as roof gardens for human use and usually require irrigation, maintenance and additional structural reinforcement of the roof (Oberndorfer etal.,2007). Extensive green roofs, sometimes referred to as ecoroofs, have substrate depths less than 20cm, require minimal or no irrigation and are generally planted with low growing succulents and stress tolerant herbaceous species (Dunnett and Kingsbury, 2004a; Oberndorfer etal.,2007). In the last two decades there has been substantial expansion of extensive green roofs in Western Europe and North America, mainly through retrofitting to existing buildings (Oberndorfer et al.,2007). However, this expansion has largely been restricted to temperate regions of the northern hemisphere. In regions unfamiliar with green roofs, such as Iran, there remain many potential barriers to their more widespread adoption.

Barriers include a lack of standards, high costs when green roof installers are inexperienced, few demonstration examples to inspire and give confidence to developers considering a green roof and a lack of relevant and reliable research to provide confidence in the economic and environmental benefits of green roofs (Dunnett, 2006; Pantalone and Burton, 2006). The last barrier is particularly relevant to countries such as Iran, which has a very different climate to the temperate regions of the northern hemisphere where green roofs are more common. Relying on northern hemisphere research, experience and technology is problematic, due to significant differences in rainfall, temperature, available substrates and suitable vegetation. This may introduce unacceptable levels of risk and unnecessary expense to development projects considering green roofs. This paper also examines green roofs in Iran, the status of the industry and discusses information gaps requiring research. While the paper uses Tehran examples, the issues identified and research required to overcome implementation barriers are common to most countries without an established green roof industry.

There are very few extensive green roofs in Tehran. The author only knows of the un-irrigated $20m^2$ experimental extensive green roof with a substrate depth of 125 mm established in the University of Tehran environmental science building as shown in Figure 2:

Figure 2: Green Roof in the University of Tehran (Personal Photo)

Technical difficulties regarding growing plants in shallow substrates in a dry and variable climate need to be overcome. Like other areas with dry or Mediterranean climates, the green roof industry in Tehran is in its infancy and some parts of the product supply chain are not well serviced. Most of the large international green roof drainage layer manufacturers are not found in Iran particularly because of the trade ban imposed by the US. Another major barrier to the widespread uptake of extensive and semi-extensive green roofs in Australia is the lack of plants that have a proven ability to survive and be aesthetically pleasing under local climatic conditions. Snodgrass & Snodgrass (2006) establish that plants to be used in green roofs need to be adapted to heat, cold, sun, wind and water deficit and be tolerant of some root inundation. Similar criteria will apply to roofs in Tehran although plants will require much greater tolerance to longer and more extreme periods of water deficit stress.

Tehran has serious and chronic water scarcity problems. Expanding populations and prolonged drought has led to significant restrictions on the use of potable water in most of Iran's major cities over the last decade (Hensher et al., 2006). Consequently, the use of large amounts of potable water to keep plants alive on green roofs is unlikely to be feasible on political or sustainability grounds and will necessitate the selection of hardy drought tolerant species that can tolerate periods of elevated temperatures and significant water deficit. However, if green roofs are to be used to effectively counter the urban heat island effect through evapotranspiration, during hot weather they will need some irrigation. This creates an inherent contradiction between one of the objectives of establishing green roofs in Australian cities and the realities of doing so. These matters will be investigated as well to ascertain the sustainability of green roofs and whether the benefit of carbon reduction outweighs the costs of maintenance in the Tehran setting.

3.0 Methodology

This chapter is primarily concerned in detailing the methods and processes to be used including sample selection, data collection and type of analysis.

3.1 Research Purpose

Marshall and Rossman (2006, p. 33) states that research is made to understand, develop or discover answers to question. Formal research can either be *exploratory, explanatory, descriptive* or a combination depending on the interests being pursued. There is no specific order on which one is higher in intellectual value. It is the quality of the research, understandability of the data analysis and rigidity of the research to inquiries made by other people

Exploratory research is used when there is an interest in understanding 'little understood phenomena' on areas where there is little or no previous research. This is usually used to discover or identify important categories of meaning and generate hypothesis for further interest. When there is an interest in determining the causes and effects of certain patterns or phenomena in question, *explanatory* research is often used (Marshall & Rossman 2006, p. 34). *Descriptive* purpose is used when the problem is clearly structured but there is no intention of investigating causal relationships (Wiedersheim-Paul & Eriksson 2001, p. 157). The study at hand aims can be considered as primarily descriptive because we are venturing into a field that is not previously investigated to a great extent.

3.2 Research Strategy

Two strategies are often used in research namely *Qualitative* and *Quantitative* (Saunders et al, 2007, p. 472). Qualitative analysis involves the logical and theory-based analysis of events to explain the relationship between variable. Minimal statistical analysis is involved. Researches that use qualitative analysis are usually descriptive and exploratory in nature because it tries to provide rich information on subjects previously not researched thoroughly. Thus, there is no established standard or statistical model of study that can be confidently used. The interest lies in seeing and understanding the patterns of behaviour of groups that includes traditions, rituals, norms and linguistic characteristics.

On the other hand, the quantitative approach is strictly formalized and the main unit of analysis is statistical data and resulting values. Wiedersham-Paul & Eriksson (2001, p. 150) considers this approach as the only "real" scientific method worthy of a high degree of confidence. The ensuing analysis provides a solid foundation for establishing patterns in different social relationships. It also provides a positivist view as there is only 'one truth'. The high regard for quantitative analysis emanates from the high formality and rigidity of structure provided by a high degree of control by the researcher (Marshall & Rossman, 2006 p. 3). Theoretical concepts are assumed to be measurable and the information gathered b the researcher is cross-analyzed to determine consistency.

For the study at hand, the chosen research approach is qualitative. The reason behind this is that we are venturing into a field of research that has not been previously investigated extensively. A highly formalized and structured approach is deemed to be unsuitable. The strategy to be used in this research will involve two qualitative approaches. A review of scientific research regarding green roof theory, design, application, outcomes and recommendations together with air pollution dynamics shall be conducted to provide a framework for applying roof garden as a means of carbon management to Tehran. The goal is to draw parallels to Tehran with areas that have implemented green roofing to manage carbon and air pollution.

In addition to the synthesis of reliable research drawing parallels with Tehran and other cities, data from existing green roof initiatives and air pollution shall be reviewed and integrated into the analysis. The research shall also involve an analysis of the viability and sustainability of roof gardens by acquiring data on water requirements, applicable flora and other considerations. This will then be analyzed with respect to the prevailing conditions of urban Tehran with the literature review serving as the basis.

Conclusion

Hopefully, the result of this research shall be a determination of sustainability of green roofs in water-thirsty and logistically-limited Tehran as well as the achievable benefits of such endeavour in air pollution and carbon management. Essentially, the goal is whether the benefits associated with implementing roof gardens can justify the costs.

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