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Benefits of green roofs; a review paper

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ABSTRACT

Green roofs bring ecosystem benefits in urban context, including building energy performance, improved air quality, air pollution mitigation, Urban Heat Island (UHI) mitigation, improved runoff water management, increased roof lifetime span, agricultural productivity, improved physical and mental public health, increased aesthetic values of urban areas, noise pollution mitigation, improved photo-voltaic panels efficiency and improved urban wildlife habitat. This paper reviewed, analyzed and discussed the previous studies for these benefits. The results from these studies acknowledged the capability of green roofs as a key element in order to improve the quality of urban areas. Therefore, this article recommends the implementation of green roofs in urban areas as a key factor in urban sustainability and development. Future research into green roofs technology is recommended in order to evaluate the efficiency of green roofs compared to other approaches aiming to improve the sustainability of urban areas.

Introduction

Rapid urban sprawl and extensive modification of landscape have been recently seen in many countries due to rapid economic growth (Yeh & Xia, 2001).The urbanization process has several intense negative effects on urban environment. One of them is a significant hydrological effect in terms of changing the nature of run-off water and other hydrological traits, influencing the rates of erosion and releasing contaminants to streams (Goudie, 2013). Urbanization also brings dark surfaces and less vegetation to urban areas than their surroundings. These manipulations to the environment affect the habitability, living quality and energy use of cities (Gartland, 2011). The reduced vegetation and dark surfaces increase the air temperature and decrease relative humidity over cities compared to that in rural areas and create urban heat island (UHI) (Gartland, 2011; Rosenfeld et al., 1995) and consequently intensify the air pollution (Rosenfeld et al., 1995; Summers, 1965). Lack of vegetation deteriorates the biodiversity of flora and fauna in urban areas and as a result endangers the native wild life. Providing more greenery system is a proper answer to the recent calls for a greener and more ecological urbanization (Dunnett & Kingsbury, 2004; Onmura, Matsumoto, & Hokoi, 2001; Van Herzele & Wiedemann, 2003; White, 2002) Unfortunately, the intolerable burden of land cost and the high quantity of impermeable surfaces (Ferguson, 1998)leads to many difficulties in providing green areas. Considering the huge amount of unused roof area (about 40–50%) of the impermeable surfaces in urban areas (Dunnett & Kingsbury, 2004); they are abandoned and useless surfaces that reduce the aesthetic value of cities besides other problems like creation of hot spots in urban regions (Gartland, 2011). Green roofs – also known as vegetative roofs, eco-roofs or rooftop gardens– may be a promising option that improves the urban quality regarding mentioned problems. A Green roofs also has an effect on the UHI via increasing water evapotranspiration (Bass, Stull, Krayenjoff, & Martilli, 2002; Gartland, 2011; Susca, Gaffin, & Dell'Osso, 2011; Von Stülpnagel, Horbert, & Sukopp, 1990)and may reduce the energy demand for heating and cooling of buildings (H. Castleton, V. Stovin, S. Beck, & J. Davison, 2010; Niachou, Papakonstantinou, Santamouris, Tsangrassoulis, & Mihalakakou, 2001; Wong, Cheong, et al., 2003). Besides, this techniques, supports the endangered flora and fauna and abate the air pollution through several processes (Baker & Brooks, 1989).

Types of green roofs

There are two main types of green roofs; extensive and intensive. Extensive green roofs have a soil/substrate layer of not more than 15cm in depth. As a consequence of the shallow substrate depth, the variety of plant species is restricted to low-growing vegetation types comprising; sedums, moss and grasses (Council, 2009). Sedum species usually include the main part of the vegetation. Sedums are succulent plants, by which they retain water in their leaves and this specification make them dramatically drought resistant. They are tiny plants that grow horizontally rather than vertically, offering protection of roof membranes and good coverage. After installation of water proofing and drainage layers in green roofs, the mats of Sedum can be easily rolled onto a roof. In other words, they are easy to install and need minimum maintenance as part of a roofing system. This kind of vegetation has potential to be installed on pitched surfaces (H. F. Castleton, V. Stovin, S. B. M. Beck, & J. B. Davison, 2010). In this case, the maximum slope angle is 45°C (Mentens, Raes, & Hermy, 2006). Design of extensive green roofs is not based on a regular accessibility basis. As a result, the structural requirement for the roof could be reduced to the least. Nevertheless, partial accessibility to the roof for maintenance is important (Council, 2009).

Intensive is generally attributed to those structures that have a higher depth of growing medium or soil, which provides the potential for a larger diversity in type and size of vegetation. This diversity usually needs supplemental irrigation and considering maintenance issues needs more attention (Weiler& Scholz-Barth, 2009).Architectural features such as ponds, seating areas, waterfalls and the like can be a part of an intensive green roof system. This type of roof can provides recreational areas where people can interact with nature and communicate with each other. These systems can retrofit forgotten and

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ugly rooftop spaces by creating active areas for play and meditation(Velazquez, 2005).

Table 1-Extensive VS. Intensive Green roofs (Velazquez, 2005)

Low-Profile Ecoroofs	High-Profile/ Roof Gardens
Low growth Media: 2.5-15 cm	>15-38 cm and deeper
Lightweight:58-244 kg/m^2	Heavier weights:244 kg/m^2+
Low growing plants: 2.5-60 cm Height	Trees, shrubs and more
Less variety of plants: Alpine types, succulents, herbs, some grasses and mosses	Depending on load, design and budget
Usually non-accessible	Designed for human recreation
Slopes up to 30°C and higher	Relatively flat
Less expensive	More expensive
Low water requirements	Irrigation usually necessary
Low maintenance	Higher maintenance

History of green roofs

Mixing vegetation with architecture is not a new idea; neither are green roofs. Since early times, created and natural landscapes have been integrated into the urban fabric. Designed uplifted green spaces have been available since humankind has been involved in architecture. Using garden designs and natural areas is an artistic expression of living space manipulation which connects back the humanity to nature.

Green roofs were initially used by the Ziggurats since the fourth millennium B.C for decreasing the roof exposure against solar radiation and protection from extreme colds. The pitched surfaces of the Ziggurat of Nanna, constructed approximately 2100 B.C., were covered with shrubs and trees.(Tan, Chew, & Wong, 2012; Wark & Wark, 2003).

The legendary Hanging Gardens of Babylon, which included dense roof gardens and green terraces, represent the primary known definition of roof greening technology, constructed between the 8th and 10th centuries B.C (Köhler et al., 2002; Oberndorfer et al., 2007).

Earth-sheltered sheds originating in Viking era have been discovered in Scotland and Ireland. In addition, about 1000 A.D., sod covered roofs were utilized in Scandinavia and Iceland. Afterward, early 19th century grass roofs have been introduced by settlers in northern United States and Canada (Velazquez, 2005; Wark & Wark, 2003).

"Garden cities" have been extended from Persia to Renaissance era Paris, and afterward from Russia to Berlin, New York and London. Modernist architects such as Le Corbusier, Roberto Burle Max and Frank Lloyd Wright promoted the advantages of roof gardens, and integrated them into the fabric of their projects. Remained successful modern roof gardens from the 1930s include Derry and Tom's Garden in London and five well-known Rockefeller Roof Gardens in New York, and the (Grant et al., 2003). Roof gardens nowadays can be seen all over Europe and around the globe. But the development of roof gardens from a definition of local architecture to a sustainable practical construction roofing system happened in modern Germany. There, roof gardens have grown via trial and error, the recurrent testing of materials, and eventually the development of industry codes and standards. (Velazquez, 2005; Wark & Wark, 2003).

The earliest modern green roofs were built in Germany in the 1880’s through a period of fast urbanization (Kohler & Keeley, 2005). A very flammable, cheap tar was generally used on roofs at the time and in an effort to decrease this fire vulnerability, a roofer, H. Koch, initiated covering such roofs with gravel and sand (Kohler & Keeley, 2005). These sanded-roofs were steadily inhabited by native plant-life and 50 of these original roofs were still waterproof and intact in the 1980’s (Kohler & Keeley, 2005). Green roofs on city department stores in the early 1900’s (Firth & Gedge, 2005) and the use of sod-roofs for airfield hanger camouflage during World War II (Firth & Gedge, 2005) are some examples of primary, planned, modern green roofs. The first large-scale roof garden project was built at the Free University of Berlin by Reinhard Bornkamm after the rediscovery of Koch’s roofs in the1960’s (Kohler & Keeley, 2005).Ever since, attention in green roofs has enhanced in Europe(Kohler & Keeley, 2005). However, significant interest in the United States did not occur until much later (Cheney, 2005; Liptan, 2005; Whittinghill, 2012).

Benefits of green roofs

Roof gardens afford many social and environmental benefits, particularly in cities where impervious surfaces and unappealing rooftops take over. Green roofs present many public, private, and design-based benefits from ameliorating environmental stress to producing an eco-friendly corporative image to revitalization of endangered wildlife (Velazquez, 2005). The following sections review the benefits of green roofs in more detail.

Aesthetic Improvement

Since long time ago, an effective and easy approach for beautifying the urban fabric has been urban greening (Getter & Rowe, 2006). As a part of urban greening, green roofs have the potential to improve the aesthetic quality of urban fabric and enhance the emotional quality of inhabitants.

Whether seen from the ground level or enjoyed as a public accessible mini park, roof gardens provide an aesthetically pleasing roofscape that presents humans a myriad of physical, mental and social advantages. From an aesthetic viewpoint, green roofs help to keep a pleasant living environment and to keep a balance between urban infrastructure and vegetation (Villarreal & Bengtsson, 2005). In Sweden, a key reason for installation of green roofs is aesthetic values (Bengtsson, Grahn, & Olsson, 2005).

Waste Diversion

The mechanical lifetime of a typical traditional roof is around 20 years. When conventional roofs are replaced, the previous roofing materials must be removed, carried, and will probably be located in a landfill where they not only occupy space, but may also disperse contaminants. Instead, green roofs are expected to last 45 years or longer regarding mechanical lifespan (Kosareo & Ries, 2007). This assessment is founded primarily on experimental evidences as modern green roofs are a quite new practice. Verifying this statement is the roof of the water treatment facility in Zurich, Switzerland, that was established in 1914 and retrofitted for the first time in 2005, a period of 91 years (D. Bradley Rowe, 2011).

Roof gardens can play a key role in landfill diversion by:

1- Protected from the impacts of high heat and ultraviolet light by the vegetation layer, roof gardens last considerably longer than conventional roofs (Pineo, 2009).

2- Increasing the lifespan of water-proofing membranes (Getter, Rowe, & Andresen, 2007), reduces related waste.

3- The use of recycled construction materials in the growing medium; the purely substrate based green roofs are relatively low-cost to install compared to the sedum systems; intend to recycle waste materials like broken bricks (Gedge & Kadas, 2005). They have mainly been produced using crushed brick or demolition waste comprising crushed concrete as their substrate, in an effort to imitate natural brown-field sites existing in urban environments (Gedge, 2001; Grant et al., 2003; Molineux, Fentiman, & Gange, 2009)

4- Extending the service life of heating, ventilation and air conditioning (HVAC) systems due to reduced usage. When intake air temperature is lower, large HVAC systems need less power. When intake air temperature exceeds 35 °C, power demand for the air conditioner rises and cooling potential reduces (Leonard & Leonard, 2005; Rowe & Getter, 2010).

Mitigation of Urban Heat Island (UHI) effect

An UHI is formed when natural vegetated surfaces like urban forestry and grass fields are replaced with water resistant impermeable and non-reflective surfaces that absorb a high ratio of incoming solar radiation (Taha, 1997). By planting vegetation within the built up areas of the urban fabric, high temperatures of urban areas can reduce inside the human habitats themselves and not merely in the disconnected spaces of parks. Unused urban surfaces such as the rooftops could easily be retrofitted with vegetation and modify the micro-climate of the built environment besides the local climate of the city (Alexandri & Jones, 2008).

Greenery systems ameliorate the urban heat island effect through three procedures (Rosenfeld et al., 1995; Solecki et al., 2005). First of all, vegetation shades the structures and shelters them against solar radiation. Consequently the buildings below them will have lower air temperature. In addition, Plants absorb water by means of their roots and disperse it into the environment in the form of vapor through their leaves in a process so-called evapotranspiration (Monteith, 1965). They consume the energy of solar radiation to evaporate water and as a result the energy spent for evaporation is not used to rise the air temperature and accordingly decreases the outdoor air temperature. Finally, greenery system can also be utilized as a wind break element. This effect is especially beneficial during the cold seasons (Gartland, 2011). Most of the available and recent studies conclude that roof gardens have a significant impact in UHI mitigation and qualifying urban climate (Alexandri & Jones, 2008; Bass, Krayenhoff, Martilli, & Stull, 2002; Rosenzweig, Solecki, & Slosberg, 2006).

Local Job Creation

Urban agriculture has many advantages including increased food and economic safety, community building and job creation, but is also confronted with many problems. The most important of which is land accessibility and contest with other types of land development. The use of roof gardens could wipe out this type of competition at some points and help to alleviate other concerns threatening urban agriculture like health hazards related to heavy metal pollution of food (Whittinghill, 2012). The development of green roof industry gives new job opportunities related to manufacturing, construction, plant growth, design, installation, maintenance and other services ("Green Roof Benefits," ; Velazquez, 2005).

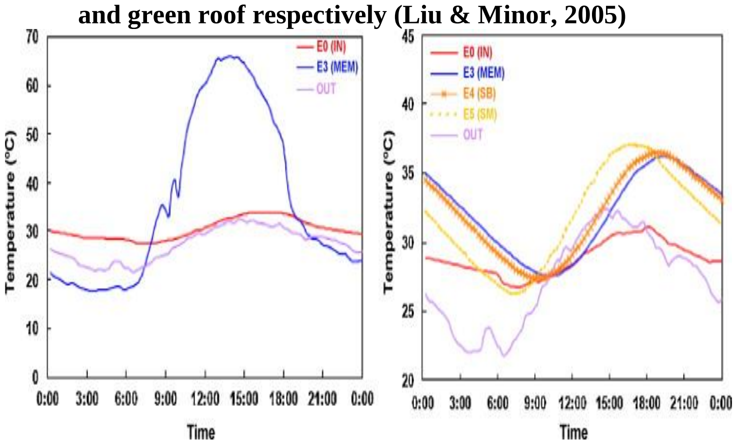
Energy performance

There are three key processes in which roof gardens help to decrease consumption of energy: providing shade, protecting buildings from cold wind and increasing insulation.

Green roof system is a passive cooling strategy that intercepts incoming solar radiation from getting the building structure below. Many studies have revealed that they can present advantages in summer cooling reduction along with winter heating (Barrio, 1998; H. F. Castleton et al., 2010; Eumorfopoulou & Aravantinos, 1998; Theodosiou, 2003; Wong, Chen, Ong, & Sia, 2003). The green roofs play a key role in the adjustment of the air temperature in the interior spaces of buildings, where they have been installed. Throughout the summer season, the exterior surfaces with the green roofs are heated less than the conventional flat roofs. Besides, in the summer season the vegetated roofs decrease the heat losses. Adding a soil layer and a layer of vegetation directly to the roof makes the building below insulated. Insulating reduces the quantity of heat transfer between outdoor and indoor environment (Barrio, 1998). The rate of heat transfer relies on the temperature difference between inside and outside. A well-insulated structure absorbs less heat in high temperatures and loses less quantity of cold air. Besides, additional insulation of green roofs makes buildings lose less quantity of heated air in wintertime. Furthermore, it adds thermal mass to help stabilizing internal temperatures year round (H. F. Castleton et al., 2010).

The estimated difference of heat transfer coefficient in non-insulated roofs with or without green roof varies from 6 to 16 W/m^{2}. Correspondingly, the overall energy saving consumption in the case of medium-insulated buildings varies from 4% till 7%.Ultimately, the effect of the green roofs on the energy savings of the well-insulated structures is about less than 2%(Niachou et al., 2001). Building energy consumption varies considerably in response to differences in role of irrigation, growing media depth, and leaf area index (vegetation density).Additionally, this reaction depends significantly on building geographical location (Sailor, 2008).

Figure 1-Summer temperature profiles for a reference roof and green roof respectively (Liu & Minor, 2005)



Finally, plants and greenery system can also be used as wind shield. This effect is useful throughout the cold seasons (Gartland, 2011). Experiments show that vegetation decrease wind velocity by 20–80 per cent, according to the canopy density (Huang, Akbari, & Taha, 1990).

Improved Air Quality

Roof gardens enhance air quality, consequently public health safety and thus a noticeable enhancement in quality of life in urban contexts (Yang, Yu, & Gong, 2008).

Vegetation in green roofs eliminates contaminants in several ways. Plants absorb gaseous contaminants via their stomata; intercept particulate substance with their branches, twigs and leaves, and have the potential of breaking down certain organic compounds such as poly-aromatic hydrocarbons in the soil or in their plant tissues (Baker & Brooks, 1989). Additionally, they indirectly decrease air-borne pollutants by reducing surface temperatures by providing shade and through evapotranspiration, which in turn reduces photochemical reactions that create contaminants like ozone in the atmosphere. For instance, when maximum daily temperatures in Los Angeles are less than 22 °C, ozone levels are below the California standard of 90 parts per billion; at temperatures above 35 °C, basically all days are smoggy (Akbari, Pomerantz, & Taha, 2001). In addition, by reducing the need for air conditioning, a lower requirement for energy results in lower emissions from power plants (Rosenfeld, Akbari, Romm, & Pomerantz, 1998). Obviously, trees has the largest effect on contaminant elimination, but grass and shrubs make considerable contributions to air quality (Akbari et al., 2001; Currie & Bass, 2008; Nowak, Crane, & Stevens, 2006; Rosenfeld et al., 1998; Scott, McPherson, & Simpson, 1998). Therefore, intensive green roofs are more effective in terms of pollution removal than extensive green roofs. Air quality improvements like reduced quantities of particulate substance, sulphur dioxide and ozone occurs throughout in-leaf season and during daylight hours (Currie & Bass, 2008). It is calculated that 0.2 hectares of grass roof can remove up to 4000 kg of particulate matter (Green, 2004; D Bradley Rowe, 2011)In the U.S. alone, (Nowak et al., 2006) calculated that urban trees eliminate 711,000 metric tons annually (Akbari et al., 2001; Nowak et al., 2006; Rosenfeld et al., 1998; Scott et al., 1998)

Urban Agriculture

Roof gardens have the potential not only include grasses, sedums, bushes domestic and other similar plants, but also fruit-bearing plant species, grasses and shrubs to provide foodstuff for urban dwellers. Respectively food production can offer educational and economic benefits to urban setting. (Dunnett & Kingsbury, 2004; Oberndorfer et al., 2007)Besides, in this case green roofs provide the opportunity of supporting local economy and as a compensation part of incomes and costs in order to support the green roofs construction (Relf, 1992) .

Run-off water management

Cities are covered by hard, impermeable surfaces that results in heavy run-off, which can make a lot of problems for existing storm water management infrastructures and result in mixed sewage overflow into rivers and lakes. As well as worsening sedimentation, erosion, and flooding, urban run-off is also high in contaminants like petroleum residues and pesticides, which damage wildlife environment and pollute drinkable supplies (Moran, Hunt, & Smith, 2005; Oberndorfer et al., 2007). Land-cover and Land-use modification may have four key direct effects on the water quality and hydrological cycle: they can cause droughts, floods, and changes in groundwater and river and, and they can deteriorate water quality (Rogers, 1994; Weng, 2001). Techniques for decreasing the high quantity of runoff through rainfall and to enhance retention include storage ponds and reservoirs where water can be temporary stored (Ferguson, 1998; White, 2002) and green spaces where water can penetrate and evaporate. However, in this case, urban hydrological system should be redesigned so that it can be more positive and active in the natural hydrological cycle. Greenery system in green roofs manages storm-water (Mentens et al., 2006; Stovin, Dunnett, & Hallam, 2007) and improves water run-off quality (Berndtsson, Bengtsson, & Jinno, 2009). Run-off water management happens through several processes: Part of the rain water is stored in the soil substrate temporarily, and to be absorbed by the vegetation and returned to the atmosphere through evapotranspiration (Christian & Petrie, 1996; Terjung & O'Rourke, 1981; Thompson, 1998). Green roofs delay runoff into the sewage system, thus help to reduce the frequency of combined sewage overflow (CSO) events, which is a significant environmental problem for many major cities.

The vegetation and the soil can also eliminate airborne contaminants taken by the rain drops, therefore improving the quality of the runoff water (Liu & Baskaran, 2003).

Roof lifetime

Plant cultivation on roof increases its lifetime in three ways; first, protects outer layers and surfaces of the roof from the damage of Ultra Violet (UV) and therefore erosion of roof materials decreases. Second, protects the roof from perforation, cracking and physical damage. This damage happens by people, trinkets and weather effects. Third, protects the green roof against effects of temperature fluctuations. As plants absorb a large amount of heat and store the energy for photosynthesis in summer months and minimize the damage caused by expansion and contraction of roof materials. Temperature of a black roof can be increased up to 80 degrees while a green roof in a similar environment has a maximum temperature of 27 degrees.

Green roof can also protect the roof in hard conditions in winter against cold and frost (Kanter, 2005; Keshtkar, 2009).

Noise reduction

Noise disturbance by road transportation is a main issue in urbanized areas (Van Renterghem & Botteldooren, 2009). Different layers and substrates employed in roof gardens can aid in mitigation of noise pollution. Federal Technology Alert states that the growing medium used in roof gardens takes up the noise of traffic and other typical external noises. By using no less than 20 cm of growing medium, noise pollution in every place can be mitigated in a range of 10 db to 46 db. This is more useful for buildings next to airports and highways (Tanner & Scholz-Barth, 2004). Nevertheless, Van Renterghem& Botteldooren (2011) claim that roof gardens might be effective in noise reduction at locations where only diffused sound waves arrive.

Financial value

In spite of the myriad quantity of research done on green roofs, current knowledge on financial value of roof gardens is inadequate. The results of a study accomplished in Manchester city showed that increasing vegetation and plants, improves its financial value of building up to 6 percent (Schwartz, 2005). Loft units with roof garden access, charge higher leasing rates than same units without roof garden access. Nevertheless, this interest is enormously complicated to quantify on paper (Luckett, 2009). Besides, using green roofs causes increasing investment opportunity (Lee R. Skabelund, 2013; Luckett, 2009)

Various species habitat

Green roofs either extensive or intensive can afford the habitat (shelter, food, water and growth location) for numerous species varied from butterflies, beetles, ants, bees and spiders to ducks and birds(Sthephan Brenneisen, 2003; Stephan Brenneisen, 2006; Coffman & Davis, 2005; Kadas, 2006). Uncommon and rare species of spiders and beetles have also been recorded on roof gardens (Stephan Brenneisen, 2006; Grant, 2006). Species richness in beetle and spider numbers on roof gardens is completely correlated with topographic variability and plant species richness (Gedge & Kadas, 2004; Oberndorfer et al., 2007).Although roof gardens cannot compensate lost habitats, but can help filling lost spaces and as it was mentioned in the report of Warning union of technology danger, they can connect fragmented roofs again.

Other benefits

Roof gardens could also be employed as fire retardant elements (Köhler, 2003). Green roofs have a small burning heat load (the heat produced when a material burns) than do current roofs ("Green Roof Benefits,"; Koehler, 2004). Also the problems raised by electromagnetic radiation (from mobile communication and wireless devices) to human well-being still remains. However, roof gardens have the potential to reduce electromagnetic radiation penetration more than 99 per cent (Herman, 2003). Besides, photovoltaic panels were 6% more efficient when installed over a roof garden (Köhler, 2006).

Conclusion

Urbanization and urban sprawl cause many difficulties and green roof technology is one of the key approaches in order to ameliorate the severity of problems. This new technology affects the economic, social, and environmental issues of urban context and serves as an urban ecosystem that can partially compensate some of the problems in urban areas. Putting vegetation on roofscape affords several economic and ecological advantages, including Aesthetic Improvement, Waste Diversion, Mitigation of Urban Heat Island (UHI) effect, Local Job Creation, Energy performance, Improved Air Quality, Urban Agriculture, Run-off water management, Roof lifetime, Noise reduction, Financial value, various species habitat, fire retardant, electromagnetic radiation penetration, efficiency of photovoltaic panels. Thus, this paper recommends using green roofs as a main strategy for decreasing the harmful impacts of urbanization and urban sprawl as well as compensating partially the shortage of greenery system.

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