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PRINCIPLES OF GREEN ROOFS DESIGN

BY

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Abstract. The implementation of green infrastructure, such as green roofs for buildings, is part of the new innovative solutions in urban design to solve the current problems related to the environment. In this context, the green roof concept has been developed as a greening solution for the building structure. This technology is part of the sustainable strategy of urban recovery. The present paper deals with the principles of design, including the classification of the green roof systems, their main components and the construction details of each type of green roof; in addition, a detailed presentation of their advantages and disadvantages is given. The paper provides an overview of the green roofs to understand this solution that can decrease the overall environmental impact of the construction sector. The authors assert that by using the green roof, the deterioration effect of the built sector over the natural environment can be significantly reduced.

Keywords: green infrastructure; greening solution; urban recovery; green roofs; principles of design; classification.

1. Introduction

Several countries that underwent a process of rapid economic growth in the last century have experienced increased urbanization. The evolution of built

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areas, like residential, commercial or industrial buildings, was done to the detriment of green areas. Moreover, this continuing process of urbanization has a negative impact on the environment and is also the principal factor behind climate changes. The construction industry has an important role regarding the present situation of the natural environment, this sector being responsible for of the 33% of greenhouse gas emission, 40% of worldwide energy use (Berardi, 2012). Due to the high rate of energy and resource consumption of the building sector, different sustainable solutions and technologies have been developed and implemented in recent years. The green roof, also named eco-roof, cool roof, vegetated roof, roof garden or living roof, basically represents the planted roof with various types of plant/vegetation in a substrate or growth medium (Francis & Lorimer, 2011; Getter *et al.,* 2009; Sailor, 2008; Ondimu & Murase, 2007). In order to encourage the implementation of vegetation on top of buildings, the concept of green roof was designed for multiple considerations, including social, economic, and environmental.

In this context, it is important to mention that greenery systems are an old technique, first designed for the Hanging Gardens of Babylon, constructed in 500 BC. The technology continued to develop in order to offer a suitable response to current issues. Modern green roofs, on a large scale, were developed and commercialized in Germany (Oberndorfer *et al.*, 2007). Even if green roof construction started in Germany, currently, countries like the USA, Canada, Australia, Singapore, and Japan borrowed the idea and expanded it using new designed construction of a green roof or retrofitting the old ones by using this concept.

Typically, a green roof is composed of several layers, including the vegetation/plants layer, the substrate/ growth medium, a filter layer, the drainage layer, insulation, the root barrier, and the waterproofing membrane. Every component has a well-defined role in the structure of the green roof system and the selection of each one is closely related to geographic location and climatic conditions (Vijayaraghavan & Joshi, 2015).

Research on green roofs has been conducted all over the world, and with the main objective of improving the elements of a green roof as well as adapting it for different climate conditions. In addition, research highlights the importance of this structure, as well as its advantages and disadvantages. According to various publications on green roof papers, it is well known that the USA contributed to 34% of the number of total published works, while researchers from countries like Europe and Asia published around 33% and 20% of the articles (Blank *et al.*, 2013). There is significant evidence that shows the value of these systems and their various benefits, such as stormwater management, the increase of urban green areas, with their wildlife habitat and ecosystems, the reduction of the urban heat island, the decrease of energy consumption costs, the reduction of noise and visual pollution, the improvement of air, and water quality, the implementation of recreative activities and the enhancement of the aesthetic value in the urban environment (Berndtsson, 2010; Niu *et al.*, 2010; Fioretti *et al.*, Getter *et al.*, 2009; Brenneisen, 2006).

2. The Main Types of Green Roof

This paper reviews the global literature from different sources, such as research articles, peer reviews, conferences, technical reports, books, in order to obtain a clear image about the main types of green roofs. Different possible classifications of green roofs systems are presented in the specialty literature.

One of the classifications of this structure presents two major categories of green roofs, extensive and intensive, but some authors include a semi-intensive category (Berndtsson, 2010; Theodosiou, 2009; Yang *et al.*, 2008; Liu & Baskaran, 2005). The classification is based on differences like substrate layer thickness, the suitable type of plants, maintenance and also the costs. In the case of an intensive green roof, the thick substrate layer is around 20-200 cm, which allows for the growth of various type of species, which attracts high maintenance, high implementation costs, and high load. One of the most important advantages of this type of green roof is the diverse selection of plants, including shrubs and small trees, besides small species, like flowers, ornamental herbs or succulents. Hence, high maintenance means periodical works like fertilizing, watering and weeding.

In opposition, the extensive green roof is characterized by a thin substrate layer, less than 15 cm, which allows just a few number of plants to grow, translating into less maintenance and low costs of implementation. Due to the thin growth medium, this category can adapt a limited selection of vegetation, like grasses, moss and few succulents. This kind of green roof is an option for the situation where no additional structural support is wanted. The last category of this classification, the semi-intensive, is a combination between the two previously presented and accommodates small herbaceous plants, small shrubs, ornamental grasses, and ground covers. In this case, the maintenance required is frequent and the implementation has high costs.

Another classification identifies four types of green roofs, as follows: intensive, semi-intensive, single-course extensive and multi-course extensive (GSA, 2011). In the report, the intensive green roofs are characterized by a substrate, more than 30 cm thick, which is suitable for a wide variety of vegetations quit similar to ground-level landscape projects, which means a larger weight. Another characteristic is the high capital needed for implementation and maintenance. One of the advantages of this type of green roof is its high water holding capacity. The second category, including the semi-intensive green roofs, has a substrate thickness of around 15-30 cm, designed with small plants, small shrubs, and grass. In order to maintain and implement this structure, the costs are high for better performance. On the other hand, the single-course extensive roofs present a substrate with a thickness between 5-7 cm. The medium growth enables just a few types of plants to develop, mostly sedum species. The most important advantage of this category is the low capital for building and reduced maintenance costs, compared with the other types of roofs. Also, these lightweight roofs are the best option for the buildings with weight restrictions. The multi-course extensive roof characterized by 10-15 cm substrate thickness is lightweight and one of the most common types of roofs in the USA. The only difference between the last two types of green roofs is the thickness of medium growth. The other characteristics are the same and this is one of the reasons why these roofs are the most common in the world.

A third classification of the green roofs takes into account the construction techniques (Kim *et al.*, 2012; Dunnet & Kingsbury, 2008; Dinsdale *et al.*, 2006). In this case, three types of green roofs can be identified: a complete system, a modular system, and precultivated blanket, Table 1. The first type is characterized by a layered system, quite heavy-weight, a complex installation which requires complex maintenance and high cost for installation. On the other hand, the modular and pre-cultivated systems are planted before being integrated above the rooftop, which means simple installation and optimized costs.

Table 1
Construction Techniques Classification of Green Roof Systems

	Complete system	Modular system	Pre-cultivated system
System	Layere system	Pre-planted	Pre-planted
Installation	Complex	Simple	Simple
Weight	High	Average	Low
Cost	High	Average	Low
Maintenance	Complex	Simple	Simple

3. Green Roof Components

In comparison with traditional rooftop gardens, green roofs are structurally designed to decrease the negative impacts of urbanization. Considering the location, climatic conditions, and local needs, green roofs are generally composed of several layers, such as vegetation, growth substrate, filter fabric, drainage layer, protection and waterproofing layer, and root barrier.

The selection of efficient green roof components is one of the most important aspects, in order to obtain an environmentally benign structure, long-term efficiency and optimized costs of installation and maintenance. This review examines the characteristics of each layer and its role, in order to identify the factors that influence their selection. For a better understanding of the structural layers of green roofs, this paper pays special attention to the extensive type, as it is one of the most common types of green roof.

3.1. Vegetation Layer

Plant selection is one of the most important and interesting parts of the development of green roofs, and its principal function is to maximize the green roof's life. The first aspect that needs to be taken into account for green roofs' success is the vegetation's health. The selection criteria for the plant's species are the following: the geographic location, the climatic conditions (the rainfall intensity, the temperature variations, humidity, wind, sun exposure), the green roofs type, depth of growth media, the growth medium type. Many authors express their opinion about choosing the plant species based on the soil depth. In this context, it can be suggested that the plant species can be selected with respect to the depth soil as presented in Table 2 (Mobasheri, 2014).

Table 2
Construction Techniques Classification of Green Roof Systems

Soil depth	Plant species
0,...,5 cm	Sedum; mosses; lichens
5,...,10 cm	Short wildflower meadows; long-growing; drought-tolerance; perennials; grasses; alpines; small bulbs
10,...,20 cm	Wildflowers; bulbs and annuals from dry habitat; low or medium perennials; hardy sub-shrubs; grasses

The plants species of a green roof are well-known for their qualities, of which the vital ones are the reduction of the heat waves in the area (Berardi *et al.*, 2012), the runoff water quality (Dvorak & Volder, 2010) and air quality (Cook-Patton & Bauerlev, 2012). It should be pointed out though that the rooftop is not normally the plants' growth space, and in this context, water represents a limiting factor and for normal development of the species, there are necessary nutrients. Taking into account the above restrictions, it can be concluded by mentioning the optimum characteristics of the vegetation for extensive green roofs, as follows:

- ability to adapt to extreme climate conditions;
- limited water necessity;

- development under minimal nutrients conditions;
- less maintenance;
- short and soft roofs;
- ability to reduce heat island phenomena;
- rapid increasing.

The species that are the most popular choice for the extensive green roofs are *Sedum* species due to their ability to perform under different climate conditions. In several studies, it is indicated that these species can have great results in order to obtain a unitary green roof, without irrigation for a longer period (Dvorak & Volder, 2010). In some studies, it was demonstrated that *Sedum* species survived and maintained their process active even after a period of 4 months without water (Durhman *et al.*, 2006).

3.2. Growth Medium

The most important layer which has a decisive influence on plant growth and on the performance of green roofs is the growth substrate. Thus, selecting the appropriate substrate can be crucial for the success of any type of green roof. Some of the green roof benefits are directly related to the physicochemical characteristics of the substrate, such as thermal benefits, peak flow reduction, water quality improvement, and sound insulation. Apart from these properties, due to some special conditions that may occur in rooftop environments, the substrate must have other special characteristics.

In this context, it was demonstrated that there is no material that possesses all the characteristics required to constitute green roof growth medium. In general practice, it is normal to mix several components of different characteristics at defined ratios. Even if many researchers constantly use commercial substrates in their experiments, there are a few authors who suggest different alternatives for the growth substrate, low cost, and light-weight. In this category, mention can be made of perlite (Zhao *et al.*, 2014; Vijayaraghavan & Raja, 2014), pumice (Kotsiris *et al.*, 2013), scoria (Cao *et al.*, 2014; Farrell *et al.*, 2012), vermiculite (Vijayaraghavan & Joshi, 2014), crushed brick (Ondoño *et al.*, 2016; Ondoño *et al.*, 2014), peat (Bisceglie *et al.*, 2014), and other low-cost waste materials (Xiao *et al.*, 2014).

It is not recommended to import growth medium from other countries, because it can lead to a high cost of implementation and also there are some pathological risks. It is always advisable to design the green roof substrate using local components, thus optimizing the costs. There is another possible solution for countries where the commercial line of these products are not developed, like garden/potting soil and composts. In this case, there are some disadvantages associated with the garden soil, such as high weight (collapse risk); support weeds; poor water retention and leach nutrients (Xiao *et al.*, 2014). Using 100% composts may also have some unwanted results on the lifecycle of the green roof and its components, like shrinkage of the vegetation support course, unnecessary growth of weeds, increased load of the roof during rainfall and damaged long term success of the whole roof.

It is very important for the growth medium to have a low dry and wet bulk density, two of the most vital factors that influence the lifecycle of the green roof. Of all component elements, the substrate represents a major load on the roof structure and on the whole building. Most of the buildings have load restrictions, like older buildings which are not designed to accommodate green roofs.

Growth mediums are expected to have high sorption capacity and less leaching tendency. Most of the authors state that there is a tendency of leaching, a fact which influences the quality of runoff.

By using all the facts previously presented, it is difficult to identify or prepare green roof substrate which presents all preferable characteristics. Some of the properties may be toned down to ameliorate the others.

3.3. Filter Layer

The main role of a filter layer is to separate the growth substrate from the drainage layer, and therefore to stop small media particles such as plant debris and soil fines from passing and blocking the drainage layer components. In general, geotextiles fabrics are used as a filter layer in the construction of green roofs (Townshend, 2007; Vijayaraghavan & Raja, 2015). The properties of these fibers which define them as a filter layer are the following: high tensile strength (to withstand the load above), good water permeability and good inhibiting for the medium particles of soil. Another role of this layer is to act as a root-barrier membrane for species that have soft and short roots. The property of absorbing a higher quantity of water, approximately 1.5 L of water/m^2, sustains the overall water retention capacity of a green roof (Wong & Jim, 2014). In different studies, it is presented that nonwoven polymer based fabric manages moisture and separates substrate layers, a fact which helps the establishment of native plants.

3.4 Drainage Layer

The success of any green roof is determined by the drainage layer. The main role of this layer is to provide an optimal balance between water and air in the green roof system. Taking into account that most of the green roof vegetation demands an aerated and non-water-logged substrate for great growth, the drainage layer helps the removal of the excess water from the substrate to ensure aerobic substrate conditions. Other important characteristics of this layer are the protection of waterproof membrane and the increase of thermal properties of green roof (Townshend, 2007). Currently, two major types of drainage layers are recommended for the green roofs:

Drainage granular materials: materials with some water holding capacity (WHC), as well as large pore spaces to retain water and also include light-weight expanded clay aggregates, crushed brick, stone crips, expanded shale, coarse gravel.

Drainage modular panels: represent a high strength plastic material (polyethylene or polystyrene) with compartments to retain water and to evacuate the excess of water.

In selecting the suitable drainage layer, the main criteria that must be observed are vegetation type, the scale of the green roof, construction requirements, and the capital cost. In the case of small-scale establishments such as residential buildings, granular materials are the best choice and satisfy the requirements. For large-scale installations, drainage modules are the most suitable and they can be implemented on flat as well as moderate slope surfaces.

3.5 Waterproofing Layer and Root Barrier

Another important component in the structure of a green roof is the waterproofing layer, which is fundamental for the success of any green roof type. On the other hand, it is possible that this layer may not be part of the green roof system, because it mostly represents a pre-requisite during any green roof installation to prevent any leak. In this context, it is well-known that any drop of water leakage in the roof can be considered as a failure of the green roof. The application of the waterproofing layer is always advisable, to prevent the removal of all the layers in case there is a problem during the installation.

Root-barrier is mandatory in the case of the intensive green roof, while for the extensive green roof, it is optional. The main property of this layer is the protection of the roof structure from the roots of plants that could penetrate from upper layers (Bianchini & Hewage, 2012). There are many types of root-barrier layers, from hard plastic sheets to metal sheets (usually copper) (Townshend, 2007).

4. Advantages and Disadvantages

Incorporating plants, growth substrate and other landscape elements on the rooftop of buildings provide several direct and indirect environmental benefits.

In this context, the impact of green roofs on the urban environment is directly connected with the type of roofs (plants species, soil depth, component materials types), the climate conditions and the characteristics of the building used as a support (age, type, structure, materials type).

Green roofs have high efficiency in reducing the level of building energy consumption in warm and cold climates and in decreasing the variation of indoor temperature (Jaffal *et al.*, 2012; Castleton *et al.*, 2010), but the building characteristics have an essential role in the impact of these structures. Being an attractive option for energy savings in the building sector, these systems reduce building energy demand by improving the thermal performance of the buildings (Saadatian *et al.*, 2013).

Green roofs are well known for their great capacity of retention of rainwater and for the delay of peak flow. Green roof represents a buffer for the pollutants, determining a good quality of stormwater runoff.

Another important advantage of green roof construction in the urban area is the reduction of air and noise pollution. The potential of green roofs in fighting pollution is well known, confirming the positive impact of these structures (Deutsch *et al.*, 2005).

The important role of large-scale green roofs in urban ecology is sustained by all scientists, yet, as they themselves conclude, measuring these benefits proves difficult (Peng & Jim, 2013).

Any type of cover has its own features that give it both advantages and disadvantages. A big disadvantage for the green roof is given by the weight it implies - because it requires more layers, and in this sense, choosing a structure that can support such a roof is absolutely necessary. Also, in the case of some types of green roof, the installation and maintenance costs may pose a problem, but these costs will be amortized by the economy of energy consumption costs, cooling costs etc.,

5. Conclusions

The present paper is rooted in the growing interest in the use of greenery systems and the vast list of journals focusing on them. Green roofs are one of the most important components of sustainable strategies and have been designed and studied all over the world in recent years. Revising recently published studies, this paper analyzes the principles of design, including the classification of the green roof systems, the main components and the construction details of each type of green roof, together with a detailed presentation of their advantages and disadvantages.

The paper provides an overview of the green roofs to the common user in order to correctly understand this solution that can reduce the overall environmental impact of the construction sector. The authors assert that by using the green roof structure, the deterioration effect of the built sector over the natural environment can be significantly reduced.

The environmental benefits of these two concepts of greening the building field include decreasing the level of energy consumption, changing urban air quality and water run-off quality, improving stormwater management, reducing noise and growing biodiversity. This paper also highlights the enhancement of water management and the decrease in air pollution through the implementation of green roofs.

The analysis in the field of the greening systems established that there is a meaningful evolution in this field. There are many advantages of these two concepts and of the impact that they have on the urban environment.

In fact, continuing to evaluate the contribution of these systems to improve building features and comparing the impact of the urban climatic condition can lead to the development of their integration in buildings. However, extensive research work is still necessary to implement policies to inspire the use of these systems.

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PRINCIPIILE DE PROIECTARE ALE ACOPERIŞURILOR VERZI

(Rezumat)

Implementarea infrastructurii verzi, cum ar fi acoperişurile verzi, este parte dintre cele mai inovative soluții de design urban care rezolvă problemele curente legate de mediul înconjurător. Această tehnologie face parte din strategia sustenabilă de refacere a mediului urban şi restaurare a construcțiilor. Este bine cunoscut faptul că acoperişurile verzi ca şi componentă a infrastructurii unui oraş poate furniza diferite ecosisteme la nivelul construcții şi la scară urbană. Prezenta lucrare tratează principiile de proiectare, inclusiv clasificarea sistemelor de acoperiş verde, principalele componente ale acestuia şi detaliile constructive ale fiecărui tip de acoperiş verde, împreună cu prezentarea detaliată a avantajelor şi dezavantajelor. Studiul oferă o imagine de ansamblu a acoperşurilor verzi pentru utilizatorul comun, pentru o clară înțelegere a acestei soluții care poate avea un impact asupra mediului înconjurător din sectorul construit. Autorii afirmă că prin utilizarea structurii acoperişului verde, efectul distructiv al sectorului construit asupra mediului natural poate fi diminuat semnificativ.