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IMPLEMENTATION OF THE SYSTEMS FOR GREENING THE BUILDING'S STRUCTURE

BY

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Abstract. In a world in continuous development, with new trends and innovative solutions to the environmental problems, the systems used for greening the building structure do not represent just surfaces covered with plants. These greening systems, like green roofs and green walls, are frequently utilized for their ecological, economic, social and aesthetical characteristics in buildings design. However, the recent technology combined in these systems can improve the functional benefits of vegetation in the building's impact on the environment and the citizens. This solution represents a part of a sustainable strategy of urban rehabilitation and buildings retrofitting. The aim of this paper is to review most of the types of greenery systems in order to identify and systematize their main characteristics and technologies involved. Therefore, it is important to understand the main differences between systems in terms of construction details

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and plant selection. The authors state that by using the green roof and green walls design, the damaging effect of the building sector over the natural environment can be significantly reduced.

Keywords: urbanization; landscape; sustainability; green roof; green walls.

1. Introduction

One of the most important issues nowadays is the relationship between the natural environment and the building sector. Urbanization and the impact of this phenomenon on climate change are the most current topics of global interest. In the most developed countries, it is predicted that the urbanization process will reach approximately 83% in 2030 (Antrop, 2004). On account of the accelerated economic development, urbanization is rising in most of the countries, debasing the natural landscape as well as the nearby environment (Ewing, 2008; Bahgat, 2010).

In the European countries, 40 % of gas emission and 20% of waste produced overall are attributed to buildings. Related to these two issues of the natural environment, experts stated that in the urban area severe weather conditions appear as a result of urbanization. The heating phenomenon is mostly caused by the anthropogenic development in the cities and the expanding of building areas (Santamouris, 2014).

Another alarming aspect is energy consumption, which represents the total processes of this sector. It is well-documented in the specialty literature that the total world energy consumption has drastically increased over the last four decades. The International Energy Agency reported that the growth of global energy used from 1971 to 2014 is around 93% (Zhang *et al*., 2012a).

Due to the high rate of energy and resource consumption in the building sector, numerous sustainable approaches and environmental technologies have been created and also implemented in the making of low-energy buildings (Zhou *et al*., 2014; GhaffariantHoseini *et al*., 2013). These new projects include energy efficient systems, advanced eco-technologies, and renewable energy sources. In this context, green roofs and living walls are two of these strategies that make buildings more sustainable (Coutts *et al*., 2013; Alexandri & Jones, 2008).

The addition of green infrastructure into buildings is part of a new perspective to resolve the current problems in the built environment. These two types of landscape projects may provide many social, economic, environmental and aesthetic benefits. Moreover, they are an important component in improving air quality, reducing pollution, reducing the temperature inside and outside the buildings, decreasing building energy usage and also improving human health.

Despite the benefits, both green roofs and living walls can be considered relatively new technologies and there are many research gaps and practical barriers before these systems can be applied. Moreover, the specific design project needs to be created according to climate conditions, urban specifications and also human needs. In recent studies, technical details of these landscape projects, plant performance and examples, storm water quantity and quality, hydrological behavior and thermal benefit have been investigated.

This paper aims to interpret and analyze the environmental benefits of the green infrastructure represented by green roofs and living walls to help understand their impact, new trends, and potential. In addition, it aims to provide a multi-disciplinary comprehension of the sustainable benefits of green roofs and living walls. These have frequently been signed as a complex system, which means a collaboration between engineers, horticulturists, landscape designers, architects, urban planners, and of course, contractors. By this approach, the present paper claims that the goals and impact of these two concepts are highly related to the goals of sustainable buildings.

The following section presents an overview of the history and evolution of these two concepts. In addition, the current interpretations, technical details and the classification of both concepts are presented. The third section focuses on the benefits and the impact on the environment. In conclusion, the future directions of research, the ultimate potential of these concepts for promoting sustainability are presented. The ways to implement them in the Romanian urban area, considering climate and urban conditions, and not the least, the needs of the citizens, are emphasized.

2. The Concepts of Green Roof and Green Wall

2.1. Evolution of the Two Concepts

The existing literature shows that several types of greening systems have been used in different countries for centuries with many benefits in various climatic conditions and building characteristics. The green roofs and also the living walls date back to the fifth century, in the Hanging Gardens of Babylon (Williams *et al*., 2010; Zhang, 2013). Recently, in many countries like Sweden, Finland, Iceland, Denmark, Norway, and the Faeroe Islands, citizens tend to cover their rooftops with sod like a solution for the extreme climatic conditions. On the other hand, the living walls were used in Mediterranean climates, as cover pergolas in vines, shading systems on the building envelope or on the building walls, to cool it down during the summer.

Since the 17th and 18th centuries, in the UK and central European countries, the use of climbing plants for building coverage increased (Newton *et al*., 2007). In the 19th century, wood decorative elements were used for aesthetic consideration in the European and North American cities (Dunnet & Kingsbury, 2008). In the 20th century, more and more investigations about green facades and green roofs were based on a new idea of ecological cities. In the beginning, the green facades were studied from a botanical perspective. During the Garden City Movement, the greening in the urban planning has marked the integration.

After a period of rare utilization during the modern times, the Swiss architect Le Corbusier rediscovered the green roofs conceptand included them in the five points of modern architecture (Eisenman, 2006). Also, at the same time, American organic architects suggested the green roofs and walls as a practice of integrating buildings in the environment.

In this context, in the 1960s, Germany started promoting the green roofs because the energy crises arose. Approximately 245.584 square meters of green facades were installed in Berlin in that period (Kohler, 2008). At first, all the research was done in Germany, Scandinavia, or Switzerland in the local language. After the green roof application initiatives, they became more and more known and popular all over the world (Shafique *et al*., 2018). The 20th century was marked by two important moments, the German Jugendstil movement (Art Nouveau) for the living walls and the publishing of guidelines for constructing green roofs, named Forschungsgesellschaft Landschaftsentwicklung Landschafsbau (FLL guidelines, 2008). Germany remains one of the main pilots and promotors of the greenery system, presently having 10% of the buildings covered with green roofs.

Nowadays, Germany's research and application of the green roof are one of the most important currents, the surface covered with green roof increasing approximately by 13.5 million m^2 every year (Saadatian *et al*., 2013). In the recent years, Japan has extensively promoted and utilized green roof as the prime technology to decrease the urban heat island, increase urban green space and encourage sustainable buildings (Shimmy, 2012).

More recently, research has mainly focused on new, low cost and innovative design of green roofs and walls, which may have numerous benefits on the environment on a large scale.

2.2. Classification and Definition

With respect to recent progress of green walls and green roofs technology, it is very important to identify and classify the existing types, according to their construction details and the main characteristics (Fig. 1).

Fig. 1 – Left: Green walls system - Continuous living wall system, Caixa Forum, Madrid, June 2013 (picture taken from Manso & Castro-Gomes, 2015). Right: Primary School at Sze Mei St, Ho Man Tin (picture taken from Zhang *et al*., 2012).

In the specialty literature, several nomenclatures attributed to all types of the green wall system are used. Some of these terms are "vertical garden" (Bass *et al*., 2003; Peck *et al*., 1999), "vertical greening system" (Perini *et al*., 2011), "green vertical system" (Pérez *et al*., 2011), "vertical greenery system" (Wong *et al*., 2010), "vertical garden", "bioshader" or "vertical landscape" (Manso & Castro-Gomes, 2015; Safikhani *et al*., 2014a; Dunnet & Kingsbury, 2008). Other terms referring to direct and indirect green facades are "direct greening systems" and "indirect greening systems" respectively (Ottelé *et al*., 2011; Perini *et al*., 2011). In addition, a new concept named "biowalls" is mentioned with reference to green walls in indoor spaces (Francis *et al*., 2011).

Green roofs are often referred to as "vegetated roofs" (Hoffman & McDonough, 2005), "cool roofs" (Xu *et al*., 2011), "eco-roofs", "living roofs" or "roof gardens" (Parizotto *et al*., 2011).

2.2.1. *Classification and Definition of Green Walls*

The concept of green walls or living walls refers to all systems that enable the greening of a vertical surface (*e.g.*, facades, walls, blind walls, partition walls, etc.) with selected vegetation and all the solutions enabling the growth of plants on, up or within the building's walls (Newton *et al*., 2007).

These systems can be divided into two main categories (Fig. 2): green facades and living walls (Kohler, 2008; Dunnett & Kingsbury, 2008). The distinction between these two types of green walls (Fig. 3) is that green facades are formed by the climbing vegetation that grows along the wall and covers it, while living walls, a more recent concept, include different materials and

technology that support a variety of plants in order to create a uniform development along the surface (Manso & Castro-Gomes, 2014).

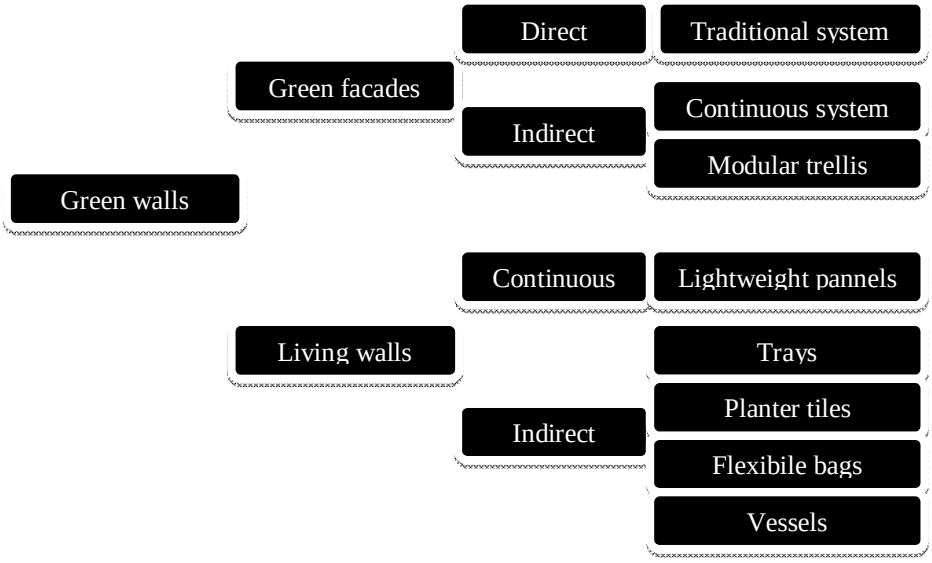

Fig. 2 – Classification of green walls, according to their construction characteristics (modified from Manso & Castro-Gomes, 2015).

Green facades are constructed by using climbing or hanging plants along the wall. The principle of these structures is based on the morphological characteristics of the plants. In traditional structures made of plants with upwards growth on the vertical surface, it consisted in using the self-clinging climbers, rooted directly in the ground. New solutions of green facades, which are indirect greening systems, use plants that can grow down the vertical surface, planted at a certain height in the vertical support structure.

Green facades can also be classified as direct or indirect structures. In the case of direct ones, the plants are attached directly to the wall, while the indirect ones include support for the vegetation.

The living walls are a new area of creativity and innovation in the domain of wall cladding. This technique creates a relationship between green walls and high buildings and also allows an immediate coverage of large surfaces with uniform growth of plants. The advantage is that living walls reach higher areas and adapt to all types of buildings. Another positive characteristic is that this structure enables the integration of a wider variety of plant species.

Fig. 3 – Examples of vertical green systems (picture taken from Perini *et al*., 2011).

The living walls systems (LWS) are further classified in the specialty literature as continuous and modular, depending on the application method. The first are based on the laying of a lightweight and permeable membrane in which the species are planted individually (Bribachi, 2011; Corradi, 2009). Patrick Blanc, the French botanist who named the continuous living wall "vertical garden", is the one who, in 1994, designed "Mur Vegetal", one of the most famous of his projects. His work helped to spread the application of this system all around the world.

In the case of the latter system (modular living walls), a specific dimension of the elements is considered, which includes the parameters for plant growth. Moreover, each element is claimed by an additional structure or it is fixed on the vertical surface. This type of wall is relatively new and varies in its assembly, composition, and weight. These walls can take the shape of trays, vessels, planter tiles or flexible bags (Manso & Castro-Gomes, 2014).

Green facades are generally more popular in Europe (Dunnet & Kingsbury, 2008; Pérez *et al*., 2014), whereas living walls have received more consideration in Asia (Pérez *et al*., 2014).

2.2.2. *Classification and Definition of Green Roofs*

The basic principle of green roofs consists in introducing various species of plants or seeds that grow in a medium on a rooftop (Snodgrass & Snodgrass, 2006). However, this simple concept has been developed into a high-technology construction solution that responds to a large area of technical demands of the building sector. According to the greening roof, two main approaches have been extensive and intensive systems (Dunnet & Kingsbury, 2008), although intermediary solutions can be found.

This classification is made based on the differences between the two types of green roof (Table 1). It depends on the vegetation type, management,

allocated usage, multilayer composition, and materials, which are, from bottom to top of the roof structure, the root barrier and waterproofing layer, protection and water retention layer, drainage layer, filter layer, substrate layer and finally the vegetation layer (FLL guidelines, 2008).

Table 1
Classification of Green Roofs and their Main Characteristics
(modified from Berardi *et al*., 2013).

Main characteristics	Extensive green roof	Intensive green roof
Growing media	<20 cm	>20 cm
Accesibility	Inaccesible	Accesible
Weight	60,...,150 kg/m^2	>300 kg/m^2
Diversity of plants	Low (moss, herb, and grass	High (perrennial species, shrubs, and trees)
Construction	Moderately easy	Technically Complex
Irrigation	Not necessary	Necesity of drainage and irrigation
Maintenance	Simple	Complicated

The prime characteristics of these typologies of the green roof concept are as follows:

The first type of structure, extensive green roofs, is designed for their aesthetic and ecological benefits, which means that public use is not allowed. One of the most important characteristics of this depth of the growing media, which is generally less than 150 mm but in the specialty literature, there are different variations of the green roof depth (Berndtsson *et al.*, 2009; Fassman & Simcock, 2012). An advantage of this structure is the lightweight with drought-tolerant and a self-seeding vegetated cover. Also, the type of plants that are used needs little or no irrigation during the roof's functional cycle. In general, the construction of this structure is made on roofs with slopes up to 33%.

The second category of green roofs, intensive green roofs also named "green gardens", is developed for public accessibility, being used as parks or buildings attraction. Therefore, they usually are designed with pavement and areas for recreation and socializing. The main characteristics of this type of green roofs are the added weight, intensive planting, higher maintenance demands, and higher costs. Plants species range from ornamental greensward to shrubs, trees. In consequence, the weight is affected by the loading of green roof and the maintenance includes more processes like reaping, fertilizing, irrigation and hoeing (Wong *et al*., 2007).

Furthermore, an intermediary green roof system can be defined, designated as a semi-intensive green roof, in which the substrate thickness

allows for more varieties of landscaping than in the case of the extensive system by implying an increased weight, maintenance, and costs.

3. Benefits of the Systems for Greening the Buildings

3.1. Benefits of Green Walls

Green walls are systems that have an impact on the urban environment because of their structure and the plants that can be installed. These complex structures have aesthetic, ecological and environmental benefits. Green walls improve the image of the buildings and create a unitary urban landscape. Since living walls may include a wider selection of plant species, they are considered more aesthetical and pleasant than green facades.

One of the most important benefits of green walls is the ecological impact. The living walls have the capacity to provide instant changing of climatic conditions in the urban area, while green facades may need several years to cover the entire wall (Perini & Roscaso, 2013; Ottelé *et al*., 2011; Dunnet & Kingsbury, 2008).

Recent studies have shown that both types of green walls, green facades and living walls, can decrease the urban heat island effect by creating a microclimate. Another important benefit, according to the urban heat island, is the capability of plants to distribute solar radiation and sensible heat during the transpiration process (Scarpa *et al*., 2014). In fact, green wall system works like an insulation layer, decreasing the heat from buildings.

Several studies have been conducted by researchers to compare the environmental performance of the main types of green walls over their life cycle (Manso & Castro-Gomes, 2014). According to these studies, direct green facades are more sustainable and economic as their structure does not require materials and they need low maintenance.

Some systems can have a decreased environmental load by contributing to the thermal resistance of the wall and determining a rebate on energy request for cooling and heating (Ottelé *et al*., 2011).

3.2. Benefits of Green Roofs

The impact of the green roofs on the urban environment depends on the type of roofs (soil depth and species), the climate conditions and elements of the building sector.

Green roofs have a high efficiency in decreasing the variation of indoor temperature and reducing the level of building energy consumption, in warm and cold climates (Jaffal *et al*., 2012; Castleton *et al*., 2010), but the building

characteristics have an essential role in the impact of these structures. In non-insulated roofs, the action of green roofs is higher than in insulated ones. In warm climates, the green roofs decrease the indoor temperature by shading the rooftop and impeding the direct action of solar radiations (Ouldboukhitine *et al*., 2011; Niu *et al*., 2010). Although the benefits of the green roof in cold climates are well known, some authors have demonstrated that the insulation with green roof structure may also have some negative impact. In Canada, for instance, the daily surface temperature variation was approximately 6ºC compared to 45ºC on a typical roof (Liu & Baskaran, 2003).

In regard to urban growth, green roofs may contribute to solving the problem of increased air pollution, urban heat island effect, and loss of habitats, as their benefits are not only at building-scale, but they embrace many important benefits at city-scale as well.

Another benefit of green roof construction in the urban area is the reduction of air pollution. It is well known that trees are the most influential plants in decreasing air pollution, according to the Urban Forest Effect Model (Currie & Bass, 2005; VanWoerf *et al*., 2005). A similar study was made for the potential of green roofs in fighting pollution, which confirmed the positive impact of these structures (Deutsch *et al*., 2005). Many studies associated the decrease of energy consumption utilizing green roofs with the indirect reduction of the level of pollution (Tan & Sia, 2005).

One of the most important environmental impacts of green roofs is the reduction of stormwater runoff (Rowe, 2011; Zhang *et al*., 2012). It has been demonstrated that green roofs could lead to about 60% runoff mitigation in the case of extensive structures and 100% for the intensive ones (DeNardo *et al*., 2005; VanWoert *et al*., 2005). To conclude, further research with respect to the important role of green roofs in water management is required to support the findings.

Last but not least, numerous studies have revealed the benefits of green roofs for the environmental quality development and ecological preservation (Rowe, 2011; Chen, 2013). The important role of the large-scale green roofs in urban ecology is sustained by all the scientists, yet, as they themselves conclude, measuring these benefits proves difficult (Peng & Jim, 2013).

4. Conclusions

The present paper is rooted in the growing interest for the use of greenery systems and the vast list of journals focusing on them. Green roofs and green walls are very important components of sustainable strategies and have been designed all over the world in recent years. Revising recently published

studies, this paper analyzes the evolution of these concepts, their definition and classification, as well as their benefits and impact on the urban environment. Findings confirm that green walls and green roofs provide a considerable amount of benefits in regard to environmental sustainability.

The analysis establishes that each concept has a significant influence on the climatic condition and the human health, whether this concerns air pollution, noise or aesthetical considerations. Identified 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.

It was found that the performance of these two concepts was not limited to the new structures; therefore, it can be a way to retrofit the building. The green roofs perform best in buildings without insulation.

This paper also highlights the enhancement of water management and decrease in air pollution through the implementation of green walls and green roofs.

The analysis in the field of the greening systems established that there is a meaningful evolution in this field. There are a lot of advantages of these two concepts and the impact that they have upon 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. Meanwhile, research is necessary to implement policies to inspire the use of these systems. Therefore, ways to easily estimate the economic impact of green walls and green roofs should be promoted.

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IMPLEMENTAREA SISTEMELOR DE ÎNVERZIRE A STRUCTURII CLĂDIRILOR

(Rezumat)

Într-o lume în continuă dezvoltare, în care primează noi trenduri şi soluţii inovative pentru rezolvarea problemelor de mediu, sistemele de înverzire ale structurilor construite nu reprezintă doar suprafeţe acoperite cu vegetaţie. Aceste sisteme de

înverzire, cum ar fi acoperişurile verzi şi pereţii verzi, sunt în mod frecvent utilizate pentru caracteristicile lor ecologice, economice, sociale şi estetice. Cu toate acestea, recenta tehnologie combinată în aceste sisteme poate îmbunătăţi beneficiile funcţionale ale vegetaţiei în impactul sectorului construit asupra mediului şi a cetăţenilor. Aceste soluţii reprezintă o parte din strategia de reabilitare şi modernizare a clădirilor. Scopul prezentei lucrări este acela de a revizui marea majoritate a tipurilor de sisteme de înverzire pentru a identifica şi sistematiza principalele lor caracteristici şi tehnologiile implicate. Prin urmare, este de un real interes înţelegerea principalelor diferenţe dintre sisteme în termeni de detalii constructive şi selecţia plantelor. Autorii susţin că utilizarea design-ului acoperişurilor verzi şi a pereţilor verzi poate diminua semnificativ efectul dăunător a sectorului construit asupra mediului înconjurător.