Green roofs – modern solutions for greening buildings

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Abstract. In a society intensively urbanized, nature and green spaces have an extremely important and determined role. Solutions that are integrating different modern techniques related to a new or an existing building, with a tremendously positive effect over the natural building and horticultural sectors will represent an important factor in reducing the negative effect over the environment on a global scale. These smart solutions could extend the garden effect from the ground to the elevated levels of the building. Even if at the present moment there are different classic solutions to realize a green roof, in the last decades, have been developed different new and modern techniques for the greening environment. Taking into account all the above mentioned, the aim of the paper is to present the modern green roof systems considering all the changes that have occurred over time, and also to analyze a series of examples of how this concept has been adopted in different parts of the world and for varies structural systems. The authors consider that the study is very important in order to completely understand the characteristics of these systems and their main components, in order to properly design and implement them according to the present environmental needs. It is believed that the knowledge of this concept and its evolution and tendencies will help solve a series of ecological and social problems.

1. Introduction
In the last decades, all over the world, it was observed a tendency of living in cities, densifying the urban population, and expanding the urban areas quickly at the expense of the green spaces [1]. The process of urbanization in its development is connected with a series of negative environmental issues, such as urban heat island effects, increased air pollution, stormwater runoff, sound pollution, and last but not least esthetical urban problems, caused by reduced green areas and chaotic building mode [2].

These unfavorable impacts are preceded by different effects, like health problems, increased psychic discomfort and anxious, social and also ecological problems, and high demand for cooling and heating of buildings, which lead to increased energy consumption [3].

Taking into account the problems previously listed, there is a tendency of searching and created a series of sustainable solutions for the new and existing buildings, to diminish the negative effects of this continuous process of urbanization [4].

The main concepts integrated into urban areas were green roof and living greenery, both important parts of the greening infrastructure used and developed in the last years [5]. In this way, the built sector became the support of these systems and the principal pilot in the actual current in terms of sustainability.
Their primary goal is not only the amelioration of the urban enlargement but the re-location of the urban areas in zones like urban forestry or dedicated green spaces.

In this context, the smart solutions of green roofs have come in the attention of society and became one of the most popular inventions used for their technical, ecological, economic, and aesthetical benefits. The expansion of the construction of the green roof has experienced an immediate spreading, now becoming part of the residential, public, commercial and government buildings. With all the positive characteristics and remarkable benefits, the researches considered that the green roof systems are the most innovative solutions of greening the buildings, in our days [6]. Researchers in Japan [7] have studied and found that the green roofs helped in the reduction of the heat flux on the order of 50%, meanwhile in Ottawa [8], the percentage is much encouraging, around 95%. Studies in Madrid [9] showed a reduction of the cooling load on an eight-story residential building with 6% during the summertime.

Taking into account all the above mentioned, the present paper has the principal aim to present the modern green roof systems considering all the changes that have occurred over time, with greater attention granted to the new technologies developed based on the oldest systems and the improvement of these systems and all its components. Another part of the paper is concentrated on analyzing a series of examples of how this concept has been adopted in different parts of the world and for various structural systems. This study has an important role in order to completely understand the characteristics of these systems and the changes appeared in the main components, in order to properly design and implement them according to the present environmental needs.

2. The modern green roof technologies

In the literature, there is a knowledge gap related to the past evolution of the green roof systems considering the materials, the technology, and the design, fact which ends with an insure connection with modern development [10].

It is well known that the roots of the green roof systems are in Antiquity, based on the development of the vernacular green roof which represents the way people tried to resists harsh environments with extreme climate [11]. On the other hand, sod-roof innovation technology continued to be honed and used from ancient to modern eras. Even if the beginning of these systems was demonstrated to be in the Ancient period, and their main benefit was to protect the people of the extreme climatic conditions, in the Middle Ages, they became an elegant symbol of the aristocratic families and religious bodies, being used as terrace garden with a particular landscape design [12]. This period was the intermediary period between the elaborated ground-level garden from the Renaissance to the artificial structures.

In the 1850s, the modern reinforced concrete technology was an important step in the evolution of the green roofs, based on the multi-story buildings with flat roofs which became the support of these systems. In 1867, the Paris World expo represented the ideal framework for promoting the technique of installing gardens on flat roofs [13].

After this incredible start, Germany integrates the spontaneous vegetation on a flat roof which is the demonstration of nature’s capacity of fixing the green roof systems on the houses [14]. This was the decisive moment for the scientific interest and which inspired and insight to make a big step from the spontaneous green roofs incidental established to the analyzed and researched green roofs systems on modern building with flat roofs.

In conclusion, a revived ancient system, green roof system was at first used for the restoration of the environment and for the protection of the roof membranes, once with the passage of time the scientific interest developed in the direction of finding different flexibility benefits, such as versatility and simplicity in design, low weight of the roof components, improved capacity of retention of the stormwater, careful selection of the plants species and also of the growing medium.

In this context, one of the best solutions developed in this direction is represented by the modular green roof system, which can be defined as modern efficient construction technology [5]. This greened innovation presents some advantages and defined characteristics, such as simple installation, simple and modern design, accessibility for the maintenance works and also repairing interventions using the
clicking features of modules. The modular green roof represents an advanced technology that includes innovative solutions and optional elements which makes it suitable for the extensive and intensive green roof [15].

By definition, a green roof module represents a technology for covering with a layer composed of vegetation a growing medium, a roof surface [16]. On the other hand, the modular green roof (figure 1) is the system that includes these modules, such as trays, blocks, containers, boxes and similar. As a result, these modules are the structural support for the growing medium and the plants, and also present an advantage regarding execution time, maintenance, and money. Green roof modules are a self-contained portable roof greening product that presents the same characteristics as a roof paver.

![Figure 1. The components of a modular green roof (source: https://sedumgreenroof.co.uk).](image)

In the specialty literature, modular green roof technology is presented as an energy-saving alternative and more attractive than a conventional green roof system. In order to establish the impact of these structures, it will be presented a series of advantages [17]:

- simplicity and flexibility in design and execution;
- lightweight structural components which are prefabricated and assembled on-site;
- accessibility reflected in the maintenance of the green roof;
- the possibility of integration of different devices or accessories, like solar panels, automatic irrigation system, lights, and decorative elements;
- the usage of recycling and ecological materials for the modules.

In conclusion, it can be advocated that the modular green roofs offer ecological, technological, aesthetical and well-being benefits, thus they represent a sustainable practice, by helping to fulfill the ecological dimension in the construction field [18]. The main characteristic making into account in promoting these systems is the economic benefit, sustained by the low execution and maintenance costs.

Another trend regarding green roof systems remarked in recent years, is the Hybrid Photovoltaic (PV) – green roof. This system presents an interest in matters of new alternative applications and findings, due to its combined characteristics both the green roof benefits and improvement of PV electrical yield [19]. The technology of these systems depends on the temperature of the PV modules and the surrounding ambient air temperature [20], meaning that cooler temperature improves the PV performance.
The success of this hybrid green roof is sustained by the evapotranspiration potential of a green roof which cools the surface and the temperature air, a fact that improves the performance of PV cells [21]. On the other hand, the PV panels help the impact of the green roof by reducing the sun’s exposure over the surface and by improving the evaporation rates. In a study realized in Spain, the results showed the PV – green roof efficiency compared with a PV – gravel roof, and the percentage was 1.29% in the case of PV – gazania green roof and 3.33% in the case of PV – sedum green roof [22]. Another conclusion of these experiments pointed out the importance of the plants’ selection according to their ability to adapt to different environmental conditions.

The case study conducted in Hong Kong highlighted the increased percentage of electricity produced by the PV – green roof compared with the stand-alone PV cell [23]. In this context, it can be concluded that PV technology even if it is a mature one and widely used in different parts of the world, can be improved by a green roof system that acts as an important element in a sustainable direction.

Research in the field has shown certain concerns about irrigation source of the green roofs. A solution in this direction is presented by the greywater [24]. It is well known that the greywater totaling (65-90)% of the domestic wastewater production, coming from laundry, kitchen activities, and bathroom [25]. The utilization of greywater presents other benefits like covering the water requirement for green roof maintenance and the possibility of choosing a wider variety of plants, not only succulents.

Several studies showed that greywater collected from the kitchen usually contains nutrients fact that minimizes the fertilization requirement of the plants’ layer. On another hand, there are concerns in terms of quantity and quality of these nutrients, which can be guided by the growth substrate according to some experiments [26]. Therefore, a green roof can become a filter for the greywater, taking into account the selected plants and their needs.

Taking into consideration all above mentioned, it can be concluded that green roof system represents a topic of major interest, based on the studies carried out in recent years, in terms of technology, structure, component elements, benefits and last but not least the best management practice to combat urbanization.

3. Notable modern green roof exemplars

In order to understand and to exemplify the way green roof systems developed over time, it is of overwhelming importance to analyze a series of examples of the notable modern green roof, adopted in different parts of the world, taking into account the various structural systems. The analysis was divided into three categories thus being evidenced by some of the significant modern green roofs from Europe, America and Asia.

From European countries, it is well known that France is remarkable for its elaborate and sophisticated landscape design. In the post-industrial period, many old infrastructures and installation from all France have been abandoned and left unused for a long period of time. In this context, in 1859, an obsolete railway viaduct stretched 4.7 km and 9 m above the street, was designed as a pleasant and impressive green roof system, presented in figure 3. It is known as Promenade Plantée (French for the planted promenade) or Coulée Verte (French for the green course). The entire design is composed of a diverse assemblage of plants, passing from the herbs to climbers, trees and shrubs, different species of flowers and decorative herbes, vegetation completed by a fountain, ponds and diverse water elements with unique aquatic creations. The well-vegetated surface has provided different habitats for spontaneous plants, which successfully completes the whole image of the place. This project has an important impact in the old neighborhood by adding 18500 m² of offices and 7000 m² of shops. Another advantage of this project is that it creates noise barriers and protect the surroundings from air pollutants.
Passing to another country with history in the landscape, the United Kingdom is one of the countries that have a history of pioneering green-roof designs in some cities. A formidable example is the pace-setting green roof from the heart of London, at High Street Kensington, installed in 1938. With an amazing surface around 6000 m², this structure is part of the Derry and Toms Department Store [27]. On the top of a retail structure, was built for the first time a sizeable roof garden (figure 2). Due to its attractive and varied landscape design, it remained Europe’s most elegant and elaborate roof garden. After different modifications, the green roof gains a new picture made up of three distinct genres gardens, as follows Morish Spanish, English Woodland, and Tudor Walled. With an elaborate and refreshed design completed with diversities of hard and soft landscape features, with fine crossings from formal-geometric, designed by stone arches, cloister walk, towers, clusters, flower beds, tree rows to informal-naturistic, pointed out by the woodlands, herbaceous covers, pools, and waterfalls. The structural elements of the entire green roof system [28, 29] were the following:

- bitumen waterproofing base;
- heavy drainage layer composed of loosely laid brick and ruble fragments;
- fan-shaped pipe-drain system;
- soil layer at the beginning with a width of 60 cm, increased to 90 cm for the accommodation of some species of trees;
- the vegetation layer comprises a large variety of different species starting from floricultural species, decorative herbs, shrubs up to trees of the most different.

This green roof represents a symbol for horticultural England, as it is mentioned by Bridge, in 2014 [30]. It is also known as one of the wonders of England due to the fact that it is an eminent historical garden and unique rooftop.

In another part of the world, in America, the Union Square, from San Francisco, opened in 1850 [31] was one of the few unnamed city-center public open spaces in this country. At first, the roof garden was composed of barren coastal sand dunes which some local plants, but it was later restored. In 1870, the Union Square become a public park, re-designed in 1903. The new project includes shrubs, trees, and peripheral tree rows. After the Great Earthquake of 1906, an innovative idea to build the world’s first underground car park at the park was implemented in 1910. This is the moment when the park helps to increase commercial business. This idea was better outlined in 1939 when a private company re-build in with private funds. The new park was the world’s first urban park on the top of a reinforced multi-leveled underground structure. The entire structure has four-story with 1700 parking spaces, and 160 massive columns, which represented the support of the roof garden.

Another notable American green roof system is the Casino Theatre at Broadway in New York, which is the first building with a roof garden with flowers covers, a cafe place, seats and stage [32]. It was the
first record of a green roof system in America, being completely built-in 1882. Even if it is emblematic in the history of these systems, some lessons can be learned from the project of the Casino Theatre. The main objective of this project was performances and commercial activities, which led to a largely hard-pavement with sporadic vegetation such as flower beds, herbs, and climbers in small regions. With large spaces covered by pavement and some vegetation randomly disposed of, it could be described as a rooftop entertainment space designed with some plants. Even if the project didn’t complete all the needs for which was built, its principal contribution was the rapid spread of its main idea reflected in more roof gardens built with more vegetation and better implementation.

In 2008, at California Academy of Sciences in the Golden Gate Park, San Francisco, was opened a modern museum whose main aim was sustainable design. In its top, was created a signature green roof designed with hills and domes imitates the relief of the city. This impressive green roof has an approximate surface of 17652 m², covered with 50 native wildflowers and other species that bring back urban biodiversity. The extensive green roof is composed of different indigenous ecosystems of a natural hill, a fact that attracts local wildlife and shelter. The 50000 porous trays made of coconut coir, allow roots to penetrate into adjoining trays thus forming a stable and unified substrate [33]. In this growing medium were planted different types of vegetation, especially chosen for creating a noise and air barrier, and for the thermal insulation and their evapotranspiration characteristics [34]. This exemplar of green roof excels by creating a completely natural ecosystem that offers both a new site image and various ecological, economic and sustainable benefits.

The last and not least, countries studied are Asian ones, because of culture and history in terms of landscape, architecture, engineering, and innovation. The first example is the green roof installed on the top of the Mitsukoshi Department Store in Tokyo. This roof garden was designed based on the traditional Japanese style and after the Great Kanto earthquake in 1923, the building was destroyed. The next period was marked by the construction of a relatively large number of green roofs, so this concept spreads rapidly on the territory of Japan. In this context, will be presented some exemplary cases which denoted the provision of natural space despite the intensive urban development.

Fukuoka in Kyushu, southern Japan, the Asian Crossroads over the Sea Institution, presents a special interest in this subject, due to the outstanding innovative design, which successfully combines the concepts of living wall and green roof. Due to the extensive surface of this institution, it was desirable to compensate for the loss of green spaces by creating impressive green facades that almost fully dress the walls of the building. The 15 levels of terraces were designed with a collection of flowers, herbs, shrubs, and trees. The growing medium on these terraces had a thickness of 30-60 cm, a fact that supported the planted of 50000 plants around 120 species [35]. With a height of 60 m and an area of 8300 m² of contiguous greenery, the institution’s building viewed from the park resembles a charming green hill designed with natural woodland vegetation (figure 4).
It is the largest green cover on one building in the world, a fact that provides the special design and the impressive overview [36].

The Municipal Central Gymnasium in Yahatya Park, Osake completed built-in 1996, represents another world green-roof record. The entire stadium was concealed underground by the new, innovative and impressive structure. The main arena of the stadium, which can accommodate around 10000 persons was covered by a dome with the widest span of 110 m and the greatest height of 26 m. The second stadium, the smaller one, has a 52 m wide dome [37]. These domes are the structural support of a layer of soil on which were planted different types of vegetation, thus were formed two circular green roofs. The most representative garden and the largest one measure around 14500 m² and the smaller one 2500 m². This green garden represents the first one established on the top of a sports structure and the largest green roof implemented on a domed roof.

These notable modern green roof exemplars previously presented, are just a small part of the largest specialty literature studied and represents the example of the green roof built in different parts of the world, and in a difficult period of the world’s history. They are the living proof that nature can always find its place in the crowded urban environment and in continuous motion.

In Romania, there are some examples of natural green roofs where the plants have grown spontaneously, [38], but only in the last years, the development of green roofs have been analyzed, especially for the identification of the species of plants that can adapt to the specific meteorological conditions of the geographical area. The concept of green roofs began to be implemented in isolation, without feasible studies to establishing the vegetation solutions that can successfully withstand a gap in temperature from (-30)°C in winter to +(40-60)°C in summer, the temperature is measured in the support layer for plants. The design and execution of these types of systems in the Romanian urban environment have known development in recent years, due to the appearance of a relatively large number of specialized companies. It can be noted the fact that the implementation of green roofs is mostly in private dwellings, especially houses, but can be also noticed the desire for implementation at the level of collective dwellings. Also, private companies or various chains of stores bring to the attention of the inhabitants of Romania these systems, being an example by using these.

4. Implications and conclusion
Research work regarding green roofs has been challenging and provides an open gate to opportunities and provocations for future studies and researches. As a conclusion of this study, the green roof subject is a topical topic, even if it is very much analyzed, discussed and studied one. Even if at the present moment different classic solutions of a green roof are often used in different parts of the world, in the last decades, they have been developing new, innovative, and modern techniques for greening a new or an existing building.

At the moment the attention was directed to the environmental problems, which resulted in drastic changes in the structure of the green roof and also the emergence of the latest technologies or the combining of several technologies to achieve the ecological dimension of the construction sector. Taking into account all the above mentioned, the aim of the paper was to define and analyze the modern green roof systems considering all the changes that have occurred over time. As a conclusion of this part of the study, it can be said that the modern solutions of the green roof as modular green roof or PV – green roof systems, are both innovative and special technologies that solve parts of the problems in terms of adapting the concept of green roof to the current conditions surrounding the environment. The modular green roof brings a solution to the issue of execution, in terms of time and costs, while the PV – green roof systems complement the classic green roof technology with photovoltaic panels technology that balances the benefits of the two technologies.

On the other hand, were analyzed a series of examples of how this concept has been adopted in different parts of the world as in Europe, America, and Asia. As the study highlighted, this concept has been developed in all parts of the world with greater or lower speed. Most of the time, earthquakes or tense moments in the history of a decisive country the emergence of a new solution that brings ecological, social, economic and mental benefits.
The characteristics of the different species of plants, the requested growing conditions, as well as the specificity of the location environment, are important aspects for identifying the optimal solutions of green roofs, regarding the declared purpose of reducing pollution. Plant species have different abilities to eliminate atmospheric pollutants and reduce emissions, therefore they need to be selected to maximize the improvement of air quality. The percentages of reduction for dust, ozone, and harmful gases are maximum during the growth periods of the plants, and the leaves play a major role so that the plants with permanent leaves (conifers) can give better results in the intention of reducing the polluting factors for the air.

On the other hand, Romania is a particular example that provides in recent years the need for implementation of these types of systems. Taking into account the climatic and geographic characteristics, the vegetal specifics and urban modifications, it is noted that the implementation of green roofs at the national level can raise certain problems, but also the basic concept can be adopted ease due to the flexibility of adapting the plant species.

The authors consider that the study is important in order to completely understand the characteristics of these systems and their main components, in order to properly design and implement them according to the present environmental needs. It is believed that the knowledge of this concept and its evolution and tendencies will help solve a series of ecological and social problems.

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