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# Reduction of Environmental Impacts: Absorption of Rainwater Through Green Roofs in Flood-Prone Areas

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***Abstract— A sustainable way to mitigate flood disasters is to implement green roofs in flood-prone areas. A green roof is an artificial system located on the slab of a structure capable of absorbing much of the urban runoff. A green roof is made up of several layers, and whose performance depends on the vegetation and its resilience to different climates, while its retention capacity depending on whether it is extensive or intensive. This paper reviews studies that show that the application of this system implies a decrease in the impermeability of cities and a greater number of green spaces.***

***Resumen--- Una forma sustentable de mitigar los desastres causados por inundaciones es la implementación de techos verdes en áreas propensas a inundaciones. Un techo verde es un sistema artificial situado sobre la losa de una estructura capaz de absorber gran parte de la escorrentía urbana. Un techo verde está conformado por varias capas; su rendimiento depende de la vegetación y su resiliencia ante los distintos climas, mientras que su capacidad de retención varía según sea extensivo o intensivo. Este trabajo revisa estudios que muestran que la aplicación de este sistema implica una disminución en la impermeabilidad de las ciudades y mayor cantidad de espacios verdes.***

## I. INTRODUCTION

Throughout history, the human being has caused environmental pollution of such magnitude that it can be reflected in the climate changes affecting the natural hydrologic cycle. These climate changes generate an alteration in the frequency and intensity of rainfall, which causes thousands of floods around the world. This is a big challenge for cities with large impervious surfaces, where the rapid growth of urbanization has resulted in overloaded infrastructures and services. This increases floods due to the low percentages of water absorption in the urban area. Therefore, progress must be made in the development of measures to mitigate the impact that infrastructure has on the local microclimate.

In this sense, it is necessary to increase the number of cities that adopt and implement policies and plans to promote the mitigation of global environmental impact. These measures should be in line with the goals set in the United Nations Sustainable Development Goals (SDGs) Report. As stated in SDG 11, there is a need to develop "sustainable cities and communities" [1]. This SDG is concerned with "making cities and human settlements inclusive, safe, resilient and sustainable" [1], implying the search for the sustainable development of cities for improvements in the economic, social, and environmental fields. One way of complying with this goal is to analyze solutions to the disasters caused by floods in cities that have inefficient drainage networks being one of these solutions by means of green roofs.

Green roofs can reduce quantities of rainwater runoff in big cities, where there is a high percentage of impervious surface areas accounting for an average of 40-50% of all surfaces. Thus, green roofs help increase the percentage of water absorption in urban areas, have the ability to reduce and delay the peak flow volumes in urban areas for a longer time controlling the runoff into the drainage system [2]. On the other hand, although green roofs can reduce runoff, they do not reduce the recharge of groundwater in urban areas [3].

The objective of this work is to describe and analyze the use of green roofs for the absorption of rainwater in flood-prone areas to reduce flooding. To achieve this goal, this paper has been organized as follows. First, green roofs, their advantages and their characteristics will be described. Secondly, the types of green roofs and the different layers that make up one will be classified. Thirdly, the water absorption capacity that the distinct types of green roofs have will be mentioned.

## I. GREEN ROOFS

Based on different authors' definitions, green roofs are rooftops covered with vegetation, which have numerous benefits. This paper will refer to a green roof as an artificial system that offers a green space on the slab of a structure, complemented with several layers of filters, that helps to reduce the percentage of urban runoff.

Green roofs offer several advantages such as stormwater retention, rainwater filtration, reduction in building energy cost, increase in air quality, and improvement of architecture and biodiversity, among others [4]. Also, green roofs can improve the local microclimate by reincorporating the vegetation that has been replaced by impermeable materials in areas with little natural soil. Although it has been determined by several studies that this system reduces the probability of flooding [5], it is not very used throughout the world.

According to analysis and evidence demonstrated in other investigations [6], the application of green roofs in urban areas helps to mitigate the negative effects that heavy rains have in flood-prone areas. The installation of green roofs can reduce the outflow volume of water by the evapotranspiration process from vegetation, making it a good option for water absorption that generates a peak discharge delay in the drainage system.

The main potential of green roofs is the volume reduction of rainwater through the losses of water from vegetation and the evapotranspiration process. The performance of a green roof depends on multiple factors, such as the type of substrate of the green roof, type of vegetation, weather conditions, slope and depth [2]. For the purpose of this study, only the first three factors will be developed below.

### *A. Type of green roof layers*

It is necessary to first refer to the components of green roofs, since each component of a green roof plays an important role in retaining stormwater. This provides a solution for flood-prone areas. The basic components of a green roof are described below and shown in Fig. 1.

According to [7], green roofs usually have eight layers. Vegetation is the first layer (plant level) and soil is the second (substrate layer). Although both constitute the growing media, the soil depends on the type of plants selected to determine the depth, gradation and yield requirements of these engineered soils. The third layer, called the insulation layer, could be installed above or below the waterproofing membrane, which is generally the seventh layer. When installed below, the system is called Inverted Roof Membrane Assembly (IRMA), which takes advantage of the insulation layer to protect the waterproofing membrane from UV degradation and it is required in locations with extended winter climate.

Layer number four is the filter fabric layer. It is a synthetic filter cloth that does not clog and maintains the drainage and water storage capabilities of the drainage layer.

The drainage layer, layer 5, typically has two characteristics. These are the drainage of water from the root zone of the plant and storage of water to provide moisture to the plants during periods of drought. There are three main types of drainage layers: drainage plates, granular media, and drainage mats.

The sixth layer is the root barrier which is usually made of polyvinyl chloride (PVC). It sometimes contains release agents and is required to protect the impermeable membrane from root penetration or degradation due to microorganisms.

Finally, the waterproof layer, which is situated above the roof surface, can be based on fluid-applied asphalt, torch-applied bitumen, monolayer thermoplastic, among other materials. For a long-lasting, maintenance-free life, the selection of green roof waterproofing is essential. These membranes must be elastic, resist the weight of water, be non-biodegradable and resistant to root penetration.

Usually there is another layer placed on top of the root barrier or waterproofing membrane used in some green roof system as a protection layer to prevent damage during roof construction and maintenance activities and can also be designed to have water storage and capillary capacity [7].

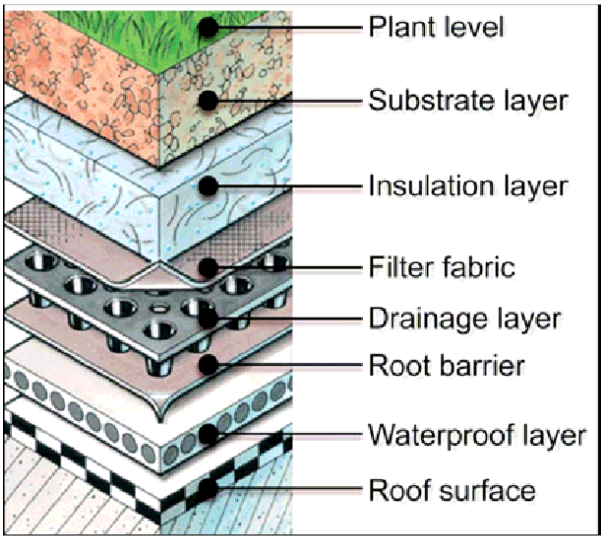


Fig. 1. Basic components of a green roof [7]

### *B. Type of vegetation*

The type of vegetation also influences green roof performance. As mentioned before, a green roof is a specialized roof system that must sustain vegetation growth in rooftop conditions that are challenging for plant survival and growth. The stress and severe drought, extreme temperatures, high light intensities, and high wind speed are the most unfavorable climate conditions that the plants must face, increasing the risk of desiccation and physical damage to vegetation and substrate. These types of roofs are usually covered with plants that grow naturally without needing sowing and with little substrate thickness required as native local plants that there are suitable to form a natural carpet [6]. These plants must have stress tolerant characteristics, such as the various *Sedum* species, grasses and herbaceous perennials, provided it is suitable for the climatic region, grown in an appropriate substrate at an appropriate depth and provided with adequate irrigation. For these reasons, *Sedum* is still the most widely used genus for green roofs [3].

### *C. Weather conditions*

Weather conditions are another important factor that affects the performance of green roofs as they are challenging for plant survival and growth. Some aspects that affect the selection of plants are the moisture stress and severe drought, extreme temperatures, high light intensities, and high wind resulting from building height. During the winter, the roofs may be subjected to strong winds and frosts, whereas in summer they will experience high levels of solar radiation. For this reason, the selection of plants should be adjusted to the weather conditions that the local ecosystem usually presents throughout the year to ensure the good performance of green roofs.

In the same line, native plants are generally considered ideal choices for landscapes because of their adaptations to local climates. They are suitable for extensive green roofs and have the necessary adaptations that enable them to survive in harsh conditions that the local climate presents [3].

## II. CLASSIFICATION OF GREEN ROOFS

After characterizing green roofs, it is necessary to refer to their classification. The eight layers presented in section II A may can be classified into three main layers called vegetation, substrate, and drainage. Depending on the depth of the soil of the substrate layer, green roofs can be classified into two main types and these types are called extensive roofs and intensive roofs, which are explained below.

### *A. Intensive green roofs*

Intensive roofs have the following characteristics. The depth of the growing media is increased, they have a depth of more than 15 cm and this is the main difference between both types of green roofs. They also contain different types of vegetation, from grass, shrubs to small trees, as well may include walkways, benches, tables and fountains on the roof as decoration. [8]

This type of green roof has a heavy weight and requires high maintenance. According to [8], "[t]he slope of an extensive green roof is less than 10° (and) [t]he intensive green roof can weigh from 171 to 391 kg / m2" [p. 368]. This means that intensive green roofs are usually big.

Intensive green roofs also have other characteristics. They have a relatively flat shape allow them to be spaces for people's recreation and interaction with nature. For the reasons given before, intensive roofs are costly and according to [9] only for the installation, the initial costs were estimated at around US$ 270 per square meter.

### *B. Extensive green roofs*

Extensive green roofs are simpler because they are lighter, thinner and require low maintenance, making them have fewer layers and, in turn, be less expensive. Extensive green roofs have drought-resistant plants; usually *Sedum* species are used. These roofs also have approximately a depth of less than 15 cm and, according to [8], an extensive green roof can weigh from 73kg/m2 to 122 kg/m2 [8].

As previously stated, plants placed on a green roof should have special characteristics. Some characteristics of extensive green roof plants are the facts that "they establish fast and reproduce efficiently; they are short in height and cushion-forming or mat-forming; their roots are shallow but spreading; and their leaves are succulent or able to store water. These types of vegetation require 2 to 20 cm of medium depth to grow." [9, p. 128].

The installation and maintenance of an extensive green roof are both more economical and relatively simpler than intensive roofs. In relation to the initial costs for an extensive green roof, they can be roughly estimated to be around US$10 per square foot [9].


Fig. 2. Extensive green roof [8, pp. 3]

From the point of view of sustainability, extensive green roofs are important because they have low weight and can be used on more rooftops, compared to the intensive type. In addition, an "[e]xtensive green roof is the least expensive among the types of green roofs in terms of installation as well as maintenance, as it can be self-retained. The installation of extensive green roofs is also easier and more flexible" [9, p. 128]. For these reasons, extensive green roofs are a suitable option.

## III. WATER ABSORPTION CAPACITY OF GREEN ROOFS

After studying the types of green roofs to address the issue of flooding prevention, it is important to focus on the performance of the water absorption capacity of green roofs. This capacity varies in extensive and intensive green roofs.

Water absorption capacity is the percentage of runoff retention, which is formally defined as the percentage of the total rainfall controlled by a green roof following a rain event. The main potential of green roofs is noted in the reduction of the water outflow volume, the losses of water from the vegetation and the evapotranspiration process from vegetation [2].

As it has already been stated, the performance of a green roof depends on the different compositions and climate conditions which can change and affect the efficiency of this system. Runoff retention results of green roofs depend on several factors. These are the age of the green roof, the pore spaces that affect the water-holding capacity of the green roof, the depth, the substrate and the type of drainage, the vegetation. As well as this, water retention does not depend on the vegetation as much as on the substrate and mainly depends on the intensity and duration of rain events. However, these factors are not as essential as the ones previously mentioned [2,9].

The intensity of rainfall and duration are the most important variables to determine how green roofs can improve the sewage system. In addition, a great difference can be observed between the retention capacity of a green roof and a conventional one because "[t]he peak discharge of small storms from vegetated roofs is lower than that from conventional roofs. On a vegetated roof, 57% of peaks were delayed up to 10 minutes compared with a conventional roof, the rainfall intensity reduced from 4.3 mm/h to an average green roof runoff rate of 2.4 mm/h. Therefore, green roofs reduced the peak intensities of water" [9, p. 131]. This advantage of green roofs over conventional ones highlights the role of the former as a water retention strategy.

In the case of extensive green roofs, the retention is around 40% to 60% of the total precipitation depending on the type of vegetation used. The most prominent difference in retention results of this type may be observed from different extensive green roofs, which depend on multiple factors such as climate conditions, roof designs, green roof slope, duration of the study, depth and type of substrate of green roof, vegetation types and the life of the green roof [2].

Table 2 shows studies about the way extensive green roof have reduced the runoff outflow compared to the ordinary roof. The average runoff retention value monitored from those studies comes to light on an average 67%, although it generally ranges between 50% and 80% [2].

| References | Runoff Retention Value Observed (%) |
| --- | --- |
| Stovin et al. (2012) [2] | 50.2 |
| Stovin et al. (2013) [3] | 59.0 |
| Seters et al. (2009) [23] | 63.0 |
| Fioretti et al. (2010) [24] | 68.0 |
| Palla et al. (2011) [25] | 68.0 |
| Carter and Rasmussen (2006) [26] | 78.0 |
| Morgan et al. (2013) [27] | 50.0 |
| Getter et al. (2007) [28] | 80.8 |
| Carpenter and Kaluvakolanu (2011) [29] | 68.3 |
| Fassman-Beck et al. (2013) [30] | 56.0 |
| Bengtsson (2005) [31] | 62.0 |
| Mentens et al. (2006) [1] | 76.0 |
| Köehler (2005) [32] | 77.0 |
| Centgraf (2005) [33] | 64.0 |
| Tillinger et al. (2006) [34] | 80.0 |
| Prowell (2006) [35] | 78.0 |
| Shafique et al. (2016) [5] | 68.0 |

Table 2. The reported average runoff retention value (%) from different green roofs studies. [2, pp. 3, Table 1]

Instead, the intensive green roof has an average rainfall runoff retention of 65.7%, depending on the covered area. Following [10], another result comparing intensive and extensive roofs shows that, both during single-day rainfalls and rainfalls occurring over several consecutive days, intensive green roofs retain about 11% more rainwater than extensive ones. Besides these observations, studies have also found that, for rainfalls of several consecutive days, the degree of reduction in the outflow of rainwater from the green roof decreases by nearly 20% [10].

## IV. CONCLUSION

Having developed the above, the following can be concluded. Firstly, green roofs are shown to be a viable and sustainable solution to flooding problems in urban areas with low levels of waterproofing and it is necessary to increase the number of cities that adopt and implement policies and plans to promote the mitigation of global environmental impact. Second, a more thorough study of the topic is necessary to be able to make a good decision when designing and building green roofs to also offer the most economical and functionally convenient green cover among the different possible options, whether intensive or extensive. Third, and as mentioned above, it is necessary to carry out a zoning study that determines the durations and intensities of rainfall in the place where the green roof system will be implemented. In addition, it is also important to consider the use of native plants suitable for green roofs that withstand the stress of growing against climatic factors and height.

It can be finally concluded that green roofs are one of the possible paths that can be taken to achieve, as initially proposed, sustainable urban plans. Sustainable urbanism is key to build modern, safe, affordable and resilient cities that ensure better developments for the population and its activities.

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The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar