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Diseño de techos verdes y jardines verticales como sistemas urbanos de drenaje sostenible en edificaciones

Design of green roofs and vertical gardens on buildings as sustainable urban drainage systems

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RESUMEN

La urbanización reduce las áreas verdes en entornos construidos que producen el aumento de la escorrentía, promoviendo las inundaciones en eventos de precipitación. En este trabajo se desarrolló un diseño de techos verdes y jardines verticales en las edificaciones de la Universidad Francisco de Paula Santander, Cúcuta, Colombia, como alternativa útil del sistema urbano de drenaje sostenible. En este sentido, se realizó el análisis estructural de las edificaciones con el software Etabs ®, en donde se comparó el diseño original con las cargas que generan las distintas categorías de techos. También, se revisaron las condiciones climáticas y ambientales para establecer las características adecuadas de los componentes de las cubiertas verdes. Se obtuvo mediante los análisis que los edificios "Bienestar" y "Civil" se encuentran capacitadas para resistir las cargas añadidas por un sistema de techo verde extensivo, siendo factible su implementación. En el diseño se generaron imágenes de los techos verdes y jardines verticales. La implementación de los sistemas de cubierta verde en las edificaciones representa una herramienta para mitigar los impactos de la urbanización y mejorar las condiciones paisajística.

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ABSTRACT

Palabras Claves:
Green roof,
Vertical garden,
Sustainable drainage

reduces vegetation in built areas, resulting in the increased runoff, causing flooding during rainfall events. This work developed a design of green roofs and vertical gardens, as a useful alternative for a sustainable urban drainage system, in buildings of the Universidad Francisco de Paula Santander, San José de Cúcuta, Colombia. The structural analysis of the buildings was carried out with Etabs® software, which was used to compare the initial design of the building without loads on the roof with the loads generated by the different types of green roofs. Climatic and environmental conditions were reviewed to establish the appropriate characteristics of the green roof components. Through the analysis of the results, it was obtained that the buildings identified as "Bienestar" and "Civil" have the capacity to resist the loads added by a green roof system identified as "extensive", so it is feasible to implement this type of green roof. Images for the design of green roofs and vertical gardens were generated. It is concluded that the implementation of green roof systems represents, in buildings, a tool to mitigate the impacts of urbanization and improve landscape conditions.

Introduction

Population growth leads to an increase in urbanized areas. The expansion of city limits generates larger built-up areas that lead to loss of vegetation. The built-up areas are impermeable surfaces that contribute to the increase of runoff volumes out of the watershed. As a consequence of vegetation loss, it also promotes pollutants associated with urbanization to be washed into water bodies [1]. New sustainable technologies through the implementation of green roofs and vertical gardens have emerged in response to the difficulty of expanding vegetated areas in urban centers [2].

Green roofs and vertical gardens are a way of incorporating plant mass into urban life in spaces that have been undervalued, such as building envelopes [3]. These systems are one of the tools that adapt to the structures, with multiple advantages over the environment. Systems for growing plants have been seen as promising tools for improving the environmental conditions of an environment, not only for aesthetic reasons, but also for improving environmental quality [4]. Plants can reduce heat by reflecting solar radiation and generating shade. They can also reduce heat through the process of transpiration, which reduces the temperature inside and outside the building [5]. In addition, plants can improve air quality by removing pollutants and trapping particles in their leaves [6].

The function of green roofs and vertical gardens as urban drainage systems lies in the fact that they are capable of retaining an average value of 69 % of precipitated water in a rainfall event under normal conditions (the percentage varies depending on the type of green roof implemented) [2]. Also, mean precipitated water retention percentages of up to 87 % have been reported [7]. The retained water is mostly absorbed by the vegetation and released back to the atmosphere by evaporation, the remaining water is stored in the substrate, which in principle reduces flood risks and improves the water balance. The systems are increasingly gaining recognition as a modern and environmentally friendly technology to address climate change and the most common environmental problems in the urban environment [2].

Some cities in Colombia are already implementing this type of technology, and the city of Bogotá already has a guide for implementing green roofs and vertical gardens in its buildings "Guía práctica de techos verdes y jardines verticales" [8]. This guide is a document prepared by the Secretariat of Environment that gathers the minimum requirements and recommended practices to apply this technology. However, this is not the case in the city of Cúcuta since it does not have these ecological systems and presents problems such as major flooding in rainy seasons, due to the existing poor storm drainage system and the long period of precipitation [9]. Particularly in the area of influence of the Universidad Francisco de Paula Santander (UFPS), Colsag Campus, there is flooding in rainfall events, as well as high temperatures in the afternoon hours, inside the classrooms of the university buildings, in addition, a high energy expenditure is generated for the classrooms with air conditioners. In this sense, the objective of this work is to develop a design of green roofs and vertical gardens in the buildings of the Universidad Francisco de Paula Santander. The purpose is to create a tool for rainwater management and generate benefits such as reducing air pollution, lowering temperatures in the buildings, improving the welfare of students with a pleasant landscape.

Materials and Methods

The study was focused on the Universidad Francisco de Paula Santander, Colsag Campus in the city of Cúcuta, Colombia. Two buildings were selected, the Bienestar Building and the Civil Building, which had structural plans and were verified by means of aerial photographs captured with a DRON belonging to the UFPS Topography laboratory. Likewise, visits were made to the facilities to compile information on the type of roofing, construction materials, uses and other descriptive data. For the development of the design of the green roofs and vertical gardens, the structural conditions, climatic-environmental conditions, possible vegetation adaptable to the design, and estimating the costs of the materials for the implementation of the green roofs were analyzed.

Structural analysis

The structural conditions of the buildings were analyzed to verify the resistance, on which the feasibility of the implementation of green roofs depends [10]. For this analysis, the guidelines of the “Reglamento Colombiano de Construcción Sismo Resistente, NSR-10 (Colombian Regulation of Earthquake Resistant Construction) [11] were followed. The structural model of the two buildings (Bienestar Building and Civil Building) was made with the help of the ETABS (Extend Tridimentional Analysis of Building System) program, following the design conditions and under the inclusion of loads of the different green roof alternatives. Displacements will be verified, corroborating both the drift, fundamental period of the structure and steel areas in the structural elements of the roof.

For the structural model, all sections were used with exactly the same dimensions and directions of the structural elements shown in the drawings. The Bienestar building has an irregular geometry and was designed with a reinforced concrete structural system, where there are also reinforcements with IPE300 type steel beams. The structure has four levels and a height of 13.9 m between floors with ribbed slabs in one and two directions. The last mezzanine also serves as a roof, since only 78% of its total area is built and the other 22% works as a roof, where it is possible to implement the green roof design for the selected buildings.

The Civil building is composed of two structures (1st Structure and 2nd Structure) joined together, where the 1st Structure rests on the 2nd Structure through a concrete bracket that only allows the transmission of vertical forces. The two structures were modeled separately, following the same procedure and considerations as the model of the Bienestar building. The same live and dead loads, seismic parameters, materials and in the same way all sections were used exactly with the dimensions and directions of the structural elements shown in the drawings. The building was designed with a reinforced concrete structural system, with four levels and a total height of 18.5 meters, mezzanines and roof with ribbed slabs in one direction, the 1st Structure has an irregular geometry of type 5P non-parallel systems and the 2nd Structure has a regular geometry.

The materials of the original design with which the buildings are constructed were used for the model. The concrete composite material with a compressive strength (f'c) of 28 Mpa, the modulus of elasticity (Ec) of 4700√f'c, and a specific weight (γ) of 2400 Kg/cm3. As for steel, the steel modulus of elasticity (Es) is 20000 Mpa and a yield strength (f'y) of 420 Mpa. The seismic parameters consisted of a high seismic hazard zone, special energy dissipation (ESD), importance coefficient (I) of 1.25, acceleration coefficient (Aa) of 0.35, velocity coefficient (Av) of 0.3, building use group III, site amplification coefficient (Fa) of 1.05, site amplification coefficient (Fv) of 1.5, soil profile type C and a structural system seismic resistance of 1.

For the load analysis, the recommendations of NSR-10, Title B, were taken into account, adding to these the loads generated by the different types of green roofs; in the case of dead loads, these do not include the dead weight of the beams, plates and columns that were also considered in the model [11], [12]. Table 1 presents the load analysis used in the structural model.

Table I. Load Analysis (KN/m2).

Interstory dead load	
Gypsum board (1cm)	0.1
Leveling mortar and flooring	1.2
Pipelines and installations	0.2
Facade and partitions for educational use	2.0
∑ (KN/m^2)	3.5
Covered dead load (Extensive green roof)	
Ceiling	0.1
Levelling mortar	1.1
Pipelines and installations	0.2
Extensive green roof	1.4
∑ (KN/m^2)	2.8
Covered dead load (Semi-Intensive green roof)	
Ceiling	0.1
Levelling mortar	1.1
Pipelines and installations	0.2
Semi-intensive green roof	2.5
∑ (KN/m^2)	3.9
Covered dead load (Intensive green roof)	
Ceiling	0.1
Levelling mortar	1.1
Pipelines and installations	0.2
Intensive green roof	4.0
∑ (KN/m^2)	5.4
Live load	
Classrooms	2.0
Corridors, stairways and balconies	5.0
∑ (KN/m^2)	7.0

Source. Authors.

Analysis of climatic factors

Most roofs are exposed to unstable environmental conditions: variable winds, direct exposure to solar radiation, variable rainfall, pollution, fluctuations in temperature, pressure, and relative humidity [8]. The vitality of green roof and vertical garden systems depends on an appropriate choice of plant species that can adapt to the environmental conditions they may face, the interaction with each component of the system and the growing medium, as well as, irrigation and general care of the plants [13].

The search, collection and analysis of the different climatic and environmental variables of the area were carried out. The information collected was taken from the meteorological station of the Universidad Francisco de Paula Santander, located at the Colsag Campus. The data were taken from September 1st, 2018 to August 31st, 2019, with hourly frequency. The data were processed to obtain the descriptions and graphs where the climatological and environmental values are presented in statistical summary form. The environmental information of the installation site will guarantee savings in economy and efficiency in the rational use of material, implementation and maintenance of these systems. Likewise, the use of climatic conditions and their compatibility with these conditions is sought.

Green roof design

The selection of the green roof system was made by comparing the main characteristics among the categories used worldwide, with emphasis on the structural conditions of the building, investment and purpose of the system. One of the categories refers to intensive green roofs which require regular irrigation and fertilizers, have a thick substrate thickness (> 15 cm), use large plants and allow for plant diversity. However, it is not recommended for constructed buildings, as they often require structural reinforcement. On the other hand, extensive green roofs are recommended for constructed buildings and may require substrate thicknesses of a few centimeters (5 - 15 cm), low vegetation diversity and minimal maintenance [1], [2].

According to the compared criteria, an extensive green roof design was chosen. Firstly, due to the weight it generates to the building, and as a result of the structural analysis, it complies with the structural parameters without affecting the buildings. In terms of investment, the extensive type system is the most favorable since it will require a low irrigation volume and, since it has a smaller number of plants and substrate, its installation and maintenance will be less costly.

In the selection of the green roof system technology, the types of technologies used were identified according to [8], considering as a criterion the favorable performance as an urban drainage system. Therefore, a monolithic multilayer type system was chosen, which offers greater functionality as a sustainable urban drainage system since it has a special drainage sheet capable of capturing rainwater, reducing the peak flow. This system also reduces the possibility of being affected by wind uplift.

Design of vertical gardens

For the stable components, the types of implementation techniques were reviewed according to [8], to determine the most appropriate, since in recent times multiple systems have been experimented and developed that optimize both their installation time and performance. Of the technologies presented in the guide, it was determined that those with bags and pots on shelves or hanging are not suitable for implementation in the university buildings, since the design is intended to have more than 50 m^2 and these techniques are for small areas or domestic uses, so that these two are discarded from the design. Another possible technique is climbing plants, although they have great benefits in terms of structure costs and others, they also have a number of disadvantages such as the time it takes to cover the entire area. In addition, if the building has any cracks, the ivy can penetrate through them and affect the facade. Therefore, the techniques considered most viable for the design of the UFPS buildings are felt layers and pot modules.

Next, the information on the design of the selected techniques was reviewed to validate that these techniques comply with the basic requirements and that a correct operation of the system is guaranteed. It was found that these types of proposals are available in the market, so the catalog of technical data sheets available for the design was used. For the location of the vertical garden, the orientation of the facades was analyzed to determine the areas that are most exposed to the maximum solar intensity, since the system is intended to help reduce the temperature inside the building. Therefore, an outdoor design was developed and based on this, active components such as vegetation were chosen.

Results and Discussion

Drifts, Fundamental Period and Steel Areas

Within the structural analysis, the maximum drifts per floor, fundamental period and steel areas of the roof beams, without green roof and then with the different green roof loads, were analyzed in order to determine the feasibility of implementation.

Table II presents the values of the fundamental period of the Bienestar building for the different types of green roofs.

Table II. Fundamental period of the Bienestar building.

No green roof	0.474
Extensive green roof	0.469
Semi-intensive green roof	0.478
Intensive green roof	0.490

Fuente: Authors

As shown in Table II, the value of the fundamental period of the bienestar building structure does not present a large increase with the different types of green roofs, being lower than the calculated maximum of 0.61, thus determining that the structure complies with the stiffness under the loads of the different types of green roofs.

Table III shows the results of the calculated drifts per floor of the welfare building loaded with the green roof alternatives, in which it is evident that, when adding a load on the roof, some of the values exceed those allowed by NSR-10, as was the case of the semi-intensive and intensive green roof loads with maximum drifts of 1.014 % and 1.052 % respectively, this makes it necessary to improve the structure for its implementation. However, the structure with the extensive green roof load complies with the maximum drift allowed by the standard, since the load generated by this type of green roof is very similar to the one taken into account in the original design, thus proving that under this requirement of the standard in the building it is feasible to implement the extensive green roof type.

Table III. Maximum drifts per floor of the bienestar structure, for the different types of green roofs.

Level	No green roof	Extensive Roof	Semi-Intensive Roof	Intensive Roof
Sense X				
Nivel	Derivative %			
N+13.9	0.4045	0.4029	0.4076	0.4183
N+10.5	0.7599	0.7516	0.7700	0.8041
N+7.0	0.997	0.9946	1.0140	1.0520
N+3.5	0.6352	0.6306	0.6416	0.6625
N+0	0	0	0	0
Sense Y				
Nivel	Derivative %			
N+13.9	0.4341	0.4574	0.4377	0.4695
N+10.5	0.7345	0.7213	0.7821	0.9163
N+7.0	0.6847	0.6741	0.7276	0.8484
N+3.5	0.3314	0.3272	0.3513	0.4272
N+0.0	0	0	0	0

Source: Authors.

For the upper and lower steel areas at the beginning, center and end of the rafter sections of the roof of the welfare building for the different types of green roofs, it was found that for the extensive green roof type there is no variation with respect to the model without green roof, and for the semi-intensive and intensive types only in some sections there is no difference with respect to the model without green roof.

Similar to the structural analysis report for the Bienestar building, the results for the Civil building are presented. Table IV shows the values of the fundamental period of the Civil building (1st and 2nd structure) for the different types of green roofs, where it is observed that the fundamental period of the structure under the inclusion of the different types of green roofs has an increase very similar to the model of the Welfare building. The fundamental period values for the Civil building exceed the calculated maximum period of 0.787s, as is the case with the semi-intensive and intensive green roof types. It can be seen that the two structures of the Civil building under the inclusion of semi-intensive and intensive green roof loads are affected and do not comply with the stiffness.

Table IV. Fundamental period of the Bienestar building.

Type	1st	2nd
No green roof	0.782	0.773
Extensive green roof	0.781	0.771
Semi-intensive green roof	0.788	0.784
Intensive green roof	0.810	0.793

Source: Authors.

Table V shows the values of the percentage of drifts, where the two structures of the civil building are affected under the different types of green roofs. As observed in the model of the Bienestar building, the drifts exceed the maximum value allowed by the regulation [11], under the semi-intensive and intensive green roof loads.

From the variation of the steel areas in the roof beams of the Civil building models, it was obtained in the analysis that some beam sections present an increase of their steel area and there is even a maximum difference of 2.27 cm^2 in the semi-intensive type and 5.68 cm^2 in the intensive type with respect to the model without green roof. Figures 2 and 3 show the beam sections affected by the increase in loads.

Tabla V. Derivas máximas por piso de la estructura bienestar, para los distintos tipos de techos verdes.

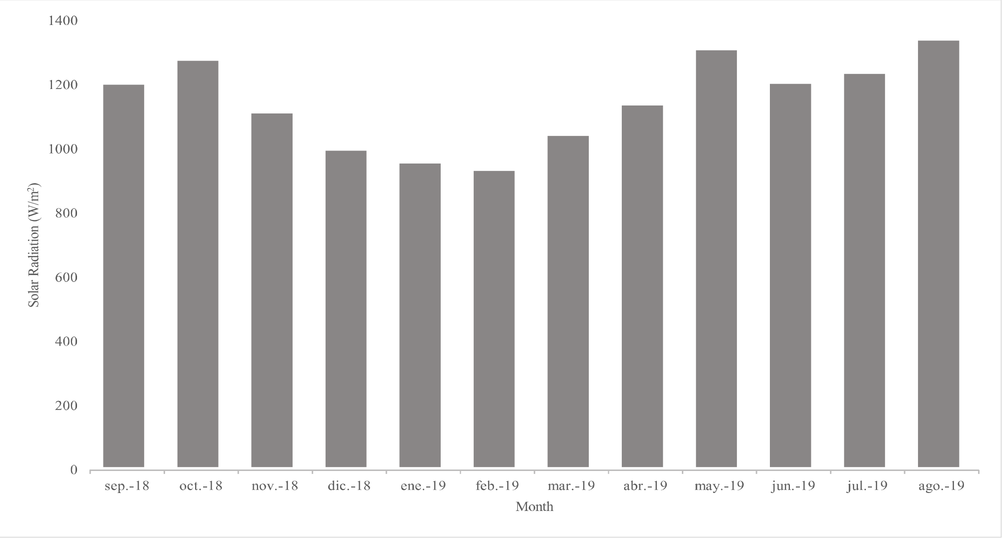
Structures	Level	No green roof	Extensive Roof	Semi-Intensive Roof	Intensive Roof
1st Structure	Sense X				
	Nivel	Derivative %			
	N+18.5	0.6188	0.6089	0.6538	0.7032
	N+14.65	0.7901	0.7333	0.8205	0.8533
	N+10.75	0.9851	0.9814	1.0130	1.0270
	N+6.85	0.9994	0.9996	1.0150	1.0110
	N+0	0	0	0	0
	Sense Y				
	Nivel	Derivative %			
	N+18.5	0.8455	0.8401	0.8816	0.9169
	N+14.65	0.9219	0.9193	0.9534	0.9757
	N+10.75	0.9600	0.9598	0.9905	1.0140
	N+6.85	0.8372	0.8355	0.8596	0.8707
	N+0	0	0	0	0
2nd Structure	Sense X				
	Nivel	Derivative %			
	N+18.5	0.7078	0.6817	0.7223	0.7741
	N+14.65	0.8789	0.8733	0.8820	0.8930
	N+10.75	0.9601	0.9594	0.9604	0.9740
	N+6.85	0.9510	0.9464	0.9534	0.9614
	N+0	0	0	0	0
	Sense Y				
	Nivel	Derivative %			
	N+18.5	0.5474	0.5319	0.556	0.5878
	N+14.65	0.7998	0.7900	0.8051	0.8261
	N+10.75	0.9980	0.9970	1.0120	1.0230
	N+6.85	0.8324	0.8321	0.8324	0.8346
	N+0	0	0	0	0

Source: Authors.

Once the structural models of the Bienestar and Civil buildings were completed and verified under the inclusion of the different types of green roofs, it was possible to verify that the implementation of the extensive green roof type is feasible for both buildings. The models did not present any non-compliance with respect to the requirements of the NSR-10 standard. Also, it was determined that the buildings under the incorporation of semi-intensive and intensive green roof loads are somewhat affected, exceeding the limits of NSR-10, which are less recommended for buildings already constructed compared to the selected category of extensive green structures [2].

Climatic-environmental conditions

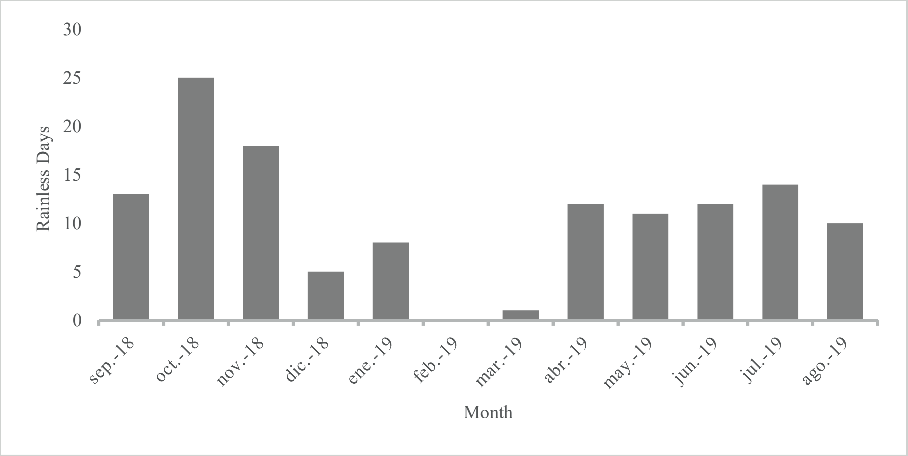
The review of the climatic-environmental conditions of the area where the green roofs are intended to be established, such as solar radiation and intensity, temperature, precipitation, humidity and wind speed, is relevant for the correct design and proper planning [14]. For the area of influence, the maximum monthly solar radiation values were obtained during the time studied (from September 01, 2018 to August 31, 2019), which mostly exceed 1000 W/m^2. The solar exposure duration in the day has a time interval from 6:00 a. m. to 7:00 p. m., with an average radiation in these hours of the day varying between 2 W/m^2 and 993 W/m2. The solar potential corresponded to an average insolation value of 5967 W/m^2/day, and the value of the average peak solar hours is 5,967 h. Graph 1 shows the maximum monthly solar radiation intensity in the study area.



Graph 1. Monthly maximum solar radiation intensity.

Source: Authors.

The annual precipitation in the area for the 12 months analyzed is 416.6 mm, with February 2019 being the driest month, with a monthly precipitation of 0 mm, while the maximum is 91.2 mm in the month of May 2019. Its average monthly precipitation is 34.72 mm. The maximum intensity rainfall event recorded a value of 1645.8 mm/h in the month of October 2018, with a precipitation of 11.8 mm. It was recorded that the longest period without rain is 57 days, time comprising from January 31st to March 28th, 2019, which is shown in Graph 2 on the days of precipitation in the study area.



Graph 2. Number of rainy days.

For the average air temperature, the average minimum temperature is 25.9 °C for the month of December and the average maximum temperature is 30.1 °C in August. Likewise, the study area has an average temperature of 27.9 °C. From the relative humidity data analyzed, it was determined that the maximum recorded is 98% for the month of October, while the minimum humidity is recorded for the months of July and August, with 30% and an average relative humidity of 66%.

Wind speed and dominant wind frequency influence the performance of green roofs and vertical gardens, since they are factors that can affect plant growth [2], [15]. It was determined that, for the study period, the maximum velocities reached had a maximum recorded value of 15.6 m/s in the month of August 2019. The dominant weather frequency varies during the year. Figure 1 shows the predominant wind direction for each month of the year, where the dominant frequency is presented in SW (South-West) and SSW (South-South-West) direction, with maximum percentages of 22 % and 63 % (Aug - 19). Winds with NNE (Northeast) and NE (North-East) components are also recorded, with a maximum percentage of 24 % and 25 % (Jun - 19).

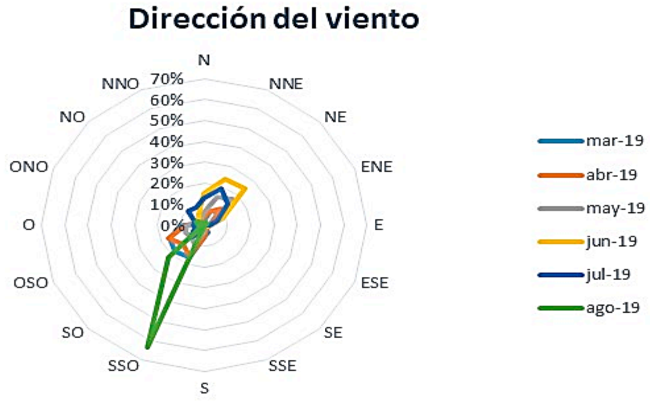


Figure 1. Wind direction by month (Mar. - 19 to Aug. - 19).
Source: Authors.

In general, the data from the station analyzed within the UFPS show that Cúcuta's climate is a local steppe climate, which in Köppen's climate classification is called BSh (Semiarid Warm Climate). The average temperature is 27.9 °C, with annual precipitation of 416.6 mm, which are characteristic of this type of climate. Regarding the most critical climatological scenarios in the area of possible implementation or installation of these sustainable urban drainage systems, the UFPS buildings face quite drastic climatic variables.

The components of the Green Roof and vertical gardens will be exposed to extreme temperatures, especially the vegetation, which must be sufficiently resistant to long periods of sun exposure and high temperatures, as well as long periods of drought. It is also revealed that the system will require artificial irrigation and a rainwater harvesting system, in order to contribute to the reuse of this water for irrigation of the vegetation cover during periods of drought, as well as for other uses that do not require the consumption of potable water.

Green roofs

The total design area of the green roof is 737 m^2 for the Bienestar building (Figure 2) and 1057 m2 for the Civil building (Figure 3), for a total of 320 m^2. Waterproofing layers will be required, an anti-root protection layer, and in case this material will be exposed to ultraviolet (UV) rays, it will require an additional layer for protection. A PVC membrane and the implementation of a drainage sheeting system are proposed [16]. Particularly, drainage sheets in comparison to granular materials do not generate higher load per square meter to the structure, are easy to install and are effective for their purpose. Likewise, showing the different types of drainage sheets, each with similar functions, it is chosen to select the Sika Drain MS20 type sheet, since it offers not only its horizontal and vertical drainage function, but also water storage. In addition, it offers greater drainage capacity and ensures ventilation of plant roots. Following the recommendations already given for the filter layer and in accordance with its performance, it was decided to select the non-woven geotextile (Sika PP 1800/2500) as the filter medium.

The plants of the extensive category roofs with poor grass, wild grasses and Sedum, it is advisable that the substrate does not contain too much humus. If soil is used for this purpose, it should not be too clayey. In general it should be depleted with sand. It should not have more than 20% of clay and silt. It is advisable to impoverish the mother soil with 25 to 75 % of light minerals of granulometry 0-16 mm. Pumice, lava, expanded slate, expanded split clay and recycled material from porous clay bricks and pumice are well suited for this purpose. Another determining factor when choosing the appropriate vegetation is the climatic conditions of the area, and according to the analyses carried out, the vegetation should withstand high temperatures, long periods of sun exposure and long periods of drought [17], [18].

Figure 2. Visualization of the green roof of the Bienestar building.
Source: Authors.

Figure 3. Visualization of the green roof of the Civil building.
Source: Authors.

Vertical gardens

The total vertical garden area in the design is 242 m^2 for the Wellness building (Figure 4) and 419 m^2 for the Civil building (Figure 5), for a total of 661 m^2. One of the plant support systems established in the design is the Naturpots modular system, which offers infinite distribution possibilities, adapting to specific design needs, both to achieve straight or angular shapes and to create curved or circular effects. One of the characteristics of this system is that it is environmentally friendly, and is made entirely of recycled polypropylene, its integrated irrigation system facilitates water supply, and its removable pots. Another is the system with felt layers, which is composed of an omega metal truss, which is screwed to the wall with a few chassis for the creation of the support frame of the vertical garden, thus creating frames with dimensions of 50 cm x 50 cm [19], [20].

Figure 4. Visualization of the vertical garden on the south façade of the Bienestar building.

Source: Authors.

Figure 5. Visualization of the vertical garden of the Civil building.

Source: Authors.

Conclusions

The Bienestar and Civil buildings under the different green roof alternatives do not present a great variation with respect to the loads of the original design; however, some of the categories exceed the values recommended in the NSR-10 regulation, as is the case of the loads generated by semi-intensive and intensive green roofs, being the extensive green roof alternative the only one that complies with these guidelines.

Climatological and environmental information is of vital importance in the design of these green roof systems, since its verification guarantees an adequate selection in the rational use of the different components of the system, especially in the selection of the vegetation cover. Regarding the design of the vertical garden, it can be said that the two selected techniques comply with the minimum design requirements according to the guidelines available at the national level, being the urban landscaping option the most expensive due to the composition of its materials, which are of recycled origin, and also because of its ease of installation and maintenance.

Green roofs and vertical gardens are promising for controlling rainwater runoff, which by means of plant structures can reduce and delay the volume of water that generates flooding. In the case of buildings, the design of green roofs represents a large surface area (320 m^2 of green roofs and 661 m^2 of vertical gardens), where their implementation, in addition to retaining water, can also result in evaporation or transpiration through plants.

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