The utilization of green roofs and walls "ecosystem services" as a strategy to mitigate climate change

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Abstract. Green infrastructure is a set of systems and strategies that promote a more sustainable and efficient development, this paper reviews the green roofs and facades that are part of this infrastructure. Currently, its application in buildings aims to take advantage of its "ecosystem services", such as energy savings, reduction of the heat island, improvements in water quality, air and health, and other advantages that are broken down into the article, which are achieved through natural processes carried out by vegetation, which allows evapotranspiration, the absorption of impurities, the reduction of noise, the capture of rainwater. Thus, collaborating in the reduction of sewage systems load in the cities, thanks to the use of the water captured, also contributing to water cost reduction from the drinking network of the cities. This paper results from a literature review on advantages and disadvantages that green roofs and walls offer in an urban environment.

1. Introduction
Architecture is dominated by an aesthetic and globalized idea, in which the environmental impact or energy expenditure was not considered, triggered a series of phenomena such as the heat island that contribute accelerating climate change and affect all living beings in our planet. However, since these phenomena have begun to affect the quality of life of human beings in an increasingly notorious way, an ecological thought has been awakened influencing disciplines such as architecture. In 2019 the European Union describes green infrastructure as a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" [1], among these we find the green roofs and walls that integrate the natural environment in the architecture and which we will deal with in this article.

The integration of vegetation in architecture is not something new, this synergy has occurred throughout history in different cultures around the world with the purpose of protection, adaptation to different climates and as crops solution. Green roofs, as we know them, were originated in the early 20th century in Germany, where vegetation was installed on roofs to mitigate the damaging effects of solar radiation on the roof structure, coinciding with a growing concern for the environment appeared in the 70s, especially in urban areas, which together with a large number of studies and regulations developed in German cities, allowed the green roof technology to be quickly adopted in terms of facades [2], vegetation has been present through climbing plants in various buildings, especially in Germany and England, where interventions were carried out on buildings using vegetation on the façade [3].

This article will analyse the advantages and disadvantages that green roofs and walls offer in sociological, environmental, functional, energy and comfort aspects, by collecting and analysing numerous state-of-the-art references on the topic.
2. Green infrastructure

In 2019 the European Commission describes Green infrastructure as "A strategically planned network of natural and semi-natural high-quality areas, designed and managed to provide a wide range of ecosystem services and protect the biodiversity of rural and urban settlements. has for objective improve the nature capacity to provide multiple and valuable goods and ecosystem services, such as clean water or air." [1] in some cities can find this infrastructure as Green roofs and walls, used to generated ecological corridors, that provide ecosystem services, but its efficiency depends of the characteristics of its substrate, vegetation and technology.

2.1. Green walls

There is no established definition, however, we can say that it’s one that allows the integration between the vegetation and architecture, by partially or totally covering vertical surfaces indoors or outdoors and that we could generally differentiate into two groups, Table 1 [4]-[6].

| Kind                   | Investment | Maintenance | Density/ height of vegetation | System   |
|------------------------|------------|-------------|-------------------------------|----------|
| Green Wall             | Traditional| low         | low                           | medium   |
|                        | Vegetable curtain or double skin | medium | low | medium | Extensive |
| Living walls           | Panel      | high        | high                          | medium/ high | Intensive |
|                        | Geotextile felt | high | high | medium/ high | Intensive |
|                        | Perimeter planters | medium | high | medium/ high | Intensive |

2.2. Green roofs

It is Vegetal coverage, installed in a horizontal area such as a building roof, allowing the integration between vegetation and architecture and usually has a similar basic configuration, however, we can differentiate into two groups, Table 2 [7], [8].

| Type                   | Investment | Maintenance | Substrate | Use               | Density an height of vegetation |
|------------------------|------------|-------------|-----------|-------------------|---------------------------------|
| Extensive Green Roof   | low        | low         | slim      | generally ecological | low/ medium                     |
| Intensive Green Roof   | high       | medium/high | heavy     | generally aesthetic | Medium/ high                   |

3. Ecosystem services

“Ecosystem Services” concept was born, for the first time, in 1977, under the name of “services of nature”, when Westman suggested cataloging the functions of the ecosystem as services in order to increase interest in biodiversity conservation, this concept generally include all the resources produced by nature, which are used by human beings directly or indirectly, and improve or favor our survival and life quality [9].

3.1. Air quality improvements

Human beings, as well as many of our activities, including construction processes, produce a carbon footprint (CO2), in many cases even causing deforestation.
Vegetated roofs and facades contribute to climate change mitigation, directly removing CO2 from the atmosphere through photosynthesis, based on several annual studies suggesting that urban areas would be neutral to their carbon production, if its natural fraction was greater than 80%, which was corroborated by M. Demuzere in 2014 [10], [11].

Vegetation also captures particles and environmental dust, which adhere to leaves, to be later eliminated with the rain, thus cleaning the air, also according to an analysis carried out by Demuzere in 2014, entitled “Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure” which, although there is little evidence available, suggests the possibility that vegetation, depending on its type and size, is capable of absorbing pollutants such as particles (PM10), black carbon and other short-lived weather pollutants [11], other research in cold climates like the one present in eastern Europe showed that, pollutants such as NO2 and O3 are clearly reduced [12], while in other areas like in the northeast of China, NO2 levels do not have a significant variation with the increase or reduction of vegetation, but O3 will behave differently, resulting in lower levels with a higher density of vegetation [13].

It is important to consider that, the capacities of green roofs and facades to eliminate environmental pollutants are linked to their location, meteorological factors, and to the correct choice of vegetation, for example, several research have shown that the concentration of pollutants is inversely proportional to the quantity of urban vegetation, which helps improving air quality, but the pollutants on which it acts will vary even by minor factors like the type of leaf vegetation, so it is difficult to stablished stable parameters whose application ensures a decrease in environmental pollutants, so each sector must establish its own parameters that allow it to take advantage of this ecosystem service [14], [15].

3.2. Temperature regulation - reduction of urban heat island effect and energy saving
The warming of cities can have consequences that range from the increase in the use of electricity due to the consumption of air conditioning, to the appearance of health problems for inhabitants, Green roofs and walls collaborate in temperature regulation. Green facades are efficient in generating shade for buildings, vegetation absorbs with its leaves part of the radiation to be used in the photosynthesis process and reflects the other part to the atmosphere, which generates a better indoor climate, with the consequent reduction of the use of energy, although as mentioned Briony and Norton in 2015, in a study carried out in Melbourne - Australia, they are not as efficient when it comes to provide shade at street level, however it significantly benefits the cooling of the city, since it captures and returns the solar rays preventing these from heating the surfaces [16].

Considering that, during the day, roofs are some of the hottest surfaces in urban areas, the use of green roofs offer great possibilities in the regulation of temperature, and so energy savings, as shown in a research carried out in 2016 by Gómez. M. et, al, where, through simulations and analysis of existing and modeled roofs in Portugal, concluded in general terms the influence on the annual energy expenditure that parameters such as the thickness of the substrate have, with an incidence capacity of 115%, the density and height of vegetation with an incidence of 38 and 7% respectively and irrigation, tested in intensive systems, with flow changes from 0 mm / day to 6 mm / day showing an incidence of around 500%[17], considering the variation in energy consumption that different combinations of these parameters pose, the choice of a suitable green roof for each environment becomes relevant.

According to several research, intensive roofs with taller and denser vegetation would be more efficient in hot or warm climates, where the highest waste of energy is for cooling, considering that the greater the vegetation the greater the evapotranspiration, which consists on the absorption of water through the roots of the plants and the emission of this through their leaves, by taking advantage of the heat present in the atmosphere to evaporate water providing moisture, which generates cooling of the surrounding air, thus reducing the temperature of the ground surface and the flow of heat through the roof and facades by absorption of radiation, collaborating not only with the reduction of energy use for cooling, but also with the reduction of the heat island effect, on the other hand, irrigation requirement will be greater cooling the covers [17]-[21].

In 2008, Alexandri and Jones study of “Temperature decreases in an urban canyon due to green walls and green roofs” in 9 cities around the world showed that the hotter and drier the climate, more important the effect of green walls and roofs in mitigating temperatures [22]. In addition, energy
savings of 32% to 100% can be achieved in the cooling of buildings, regarding green facades [23], [24], concluded that the application of grass as vertical green reduced the temperatures of the interior surface by more than 2 °C [11].

3.3. Reduction of flood problems and water quality improvement
Cities are covered with impermeable surfaces that are part of their buildings, roads, and even parks and squares, which causes alterations in the ways in which rainwater flows. In a natural environment in which there are vegetation and permeable surfaces, rainwater would be captured and used by the vegetation, as well as filtered by earth to become part of groundwater, however, in cities this does not happen and it translates into an increase in surface water runoff that can cause flooding due to saturation of the sewage system, in addition to degeneration and waste, due to polluting particles drag [25]. As has been well documented in Europe and the United States, it is green roofs that, due to their location in buildings, as well as their configuration, collaborate with water retention, since they have a layer in which rainwater is collected and stored, "being able to retain considerable amounts of rain by reducing the annual volumes of runoff in areas where rainfall is high, unlike climatic zones characterized by summer droughts and extended winter wet seasons" [18], where this capacity is not a relevant issue seen from the point of runoff, but it’s important from the point of water storage for self-sufficiency, especially in drought times.

According to several studies, green cover improves water quality, eliminating various pollutants such as phosphorus by 60% and fecal coliforms by up to 100%, according to tests by Gregoire and Clausen [26], reducing pollutants global load, since that act as a sink. Its removal efficiency will depend on the type of pollutant, as well as vegetation type, soil properties, fertilizer addition, and local climate [11], factors that can become very important when measuring pollutants in the water stored by green roofs.

Other research like the one carried out with extensive roofs in Berlin in 2014, in which it was intended to reduce pollution in the Spree river, the one carried out in Poland in 2018 or the one carried out in Colombia in 2020 in varied climates, and in which they experimented with substrates of different compositions showing that green roof substrates can be an important source of pollutants such as phosphorus, TSS, TKN, PO4, DQO, DBO, nitrogen and coliforms in runoff water, due to the ability of the substrates to remove these pollutants are affected by fertilization, organic matter, pollutants in the substrate, on the roof membranes, the thickness of the substrate, or the type of vegetation.

Additionally an intensive cover with deep substrates and higher vegetation would improve its capacity to capture water, however, if in addition to being intensive the substrate is old, it may have a higher concentration of pollutants than “newer” substrates or specifically treated to achieve that the chemical properties of its organic and inorganic components, as well as its plant species, work to achieve a cleaner runoff, therefore, the selection of plants and substrates that optimize the absorption of nutrients and pollutants can help improve the capacities of the roofs in relation to water quality, always taking into account the climatic and natural characteristics of the environment, although they can affect other ecosystem services such as the ability to save energy in ventilation heating [20], [24], [27], [28].

3.4. Acoustic isolation and urban noise reduction
The ability of vegetation to isolate us from noise, by fences that surround the buildings, has been well known practically since the construction of buildings began. In today’s cities that are increasingly filled with hard surfaces that replace vegetation, we find ourselves exposed to high levels of noise, an increase in green infrastructure in cities can reduce these noise levels since while hard surfaces of urban areas tend to reflect sound, vegetation and the substrate that make up the roofs and vegetated facades can absorb it. Vegetation works by reducing sound levels in three ways:

- Vegetable elements such as trunks, branches, and leaves can reflect and disperse noise.
- By the acoustic absorption of vegetation due to its mechanical vibrations caused by sound waves, which lead to dissipation by converting sound energy into heat.
- The reduction of sound levels due to the interference of acoustic waves in the substrate layers [29].

Research carried out to measure noise reduction levels in green infrastructures determined that “noise reduction was lower for green facades than for roofs” [30].
A comparison between a roof made of typical materials and a green roof made by Rowe determined that because the substrates used for green roofs are (highly) porous, they allow a large number of interactions between sound waves and substrate particles [31], which produces a noise attenuation, with a variation that will depend on substrate thickness, since increasing its depth up to 15 to 20 cm, improves the reduction of noise in the medium frequencies and the vegetation in the high frequencies, so that an increase in the thickness of vegetation or the use of species with more foliage could increase its acoustic insulation capabilities, however, the type of support structure and the materials to be used and the fact that there must be a physical separation between construction elements to avoid the transmission of sound [29].

3.5. Ecosystems recovery

Vegetated roofs and facades have the ability to “imitate or recreate” natural ecosystems, particularly the extensive roofs that mimic typical habitats, attracting biodiversity to these spaces. An investigation carried out by Braaker and others, on the ecological and functional value of green roofs in cities, according to the variation of biodiversity of four groups of arthropods with contrasting mobility in 40 green roofs and 40 extensive green sites on the ground in the city of Zurich, Switzerland, the study revealed that the connectivity of the habitat between surrounding green roofs promotes the exchange of insects and pollinators between the roofs, especially in regard to those with high mobility, while the less mobile groups are more influenced by local environmental conditions” [32], however, greater connectivity between green spaces could eventually even promote the exchange of low-mobility insects, collaborating with the ecological regeneration and repopulation of insects such as bees currently in danger. This can give us a reference for how effective they are for the development of biodiversity since there are very few studies on this subject. Nevertheless, wildlife is not always desirable, especially if the green roof is not designed to support biodiversity especially of animals such as birds or rodents, which could cause damage to the elements that make up the roof, or its maintenance. In addition, it should be considered that these spaces are relatively isolated from larger natural green spaces, due to the difference in height so that, although they collaborate in mitigating the lack of natural green spaces, they cannot be considered as a replacement, at least not from a biodiversity point of view of medium or large animals [18].

3.6. Green recovery and quality of life improvements

These green infrastructures contribute to the increase of urban flora and fauna, generating relaxing visual spaces, with great potential for the development of recreation and relaxation activities such as urban agriculture, contemplation of nature, meditation, etc. Exposure to these “natural” environments provide psychological benefits, reducing stress, crime, insecurity feeling, and even improving physical health, or contributing to economic and food independence as several studies have shown and which is reflected in the requirements to be met in several sustainable constructions.

For Miller and Charlie, forty years’ experience in Germany suggests that they may have value in the protection of waterproofing materials, since the multiple layers of the green roof could protect them from mechanical damage, ultraviolet radiation, and extreme temperatures, minimizing damages caused by the daily expansion and contraction of roofing materials [12], [18].

4. Discussion

Intensive and extensive Green roofs and walls systems provide a wide range of environmental benefits through ecosystem services, Table 3 shows a resume of the environmental benefits of intensive and extensive systems, however it is important to understand that to determine the most effective system to be used, first must be know the climatic and even constructive conditions of the environment, therefore, it cannot be taken as a base applicable to all environment, and is susceptible to changes according to the particular characteristics of the vegetation, the type of substrate, fertilizers, pollution levels, climate, among others.
Table 3. Resume environmental benefits of intensive and extensive systems.

| System   | Air Quality Improvements / Temperature Regulation | Water quality improvement / flood | Acoustic Isolation and Urban Noise Reduction | Green Recovery and Quality of Life Improvements |
|----------|--------------------------------------------------|---------------------------------|---------------------------------------------|-----------------------------------------------|
| **Extensive** | high air permeability | low capacity in water collection | low reflection and dispersion                  | Increase in biodiversity                       |
|          | low evapotranspiration                      | low water consumption          | low Isolation and absorption                  | Improvements in quality of life and health    |
|          | low shade possibilities                      |                                 | low destruction of acoustic waves             |                                               |
|          | Medium radiation absorption                  |                                 |                                               |                                               |
|          | high pollutant removal                       |                                 |                                               |                                               |
| **Intensive** | low air permeability                       | High capacity in water collection | low reflection and dispersion                  | Increase in biodiversity                       |
|          | high evapotranspiration                      | high water consumption         | low Isolation and absorption                  | Improvements in quality of life and health    |
|          | high shade possibilities                      |                                 | low destruction of acoustic waves             |                                               |
|          | high radiation absorption                    |                                 |                                               |                                               |
|          | low pollutant removal                        |                                 |                                               |                                               |

5. Conclusions
The use of vegetated roofs and facades can collaborate with climate change effects mitigation, and their contributions will be greater the more widespread they are since their ecosystems not only act on the building in which they are installed but also their benefits extend to the environment, so its use in cities could be used to solve various problems such as pollution caused by industry, the high number of vehicles; the risks of flooding due to climatic factors, weaknesses in its sewage systems; or even combat the heat island.

However, one of the factors in which their collaboration, although little documented is of great importance, is in the recovery of ecosystems and green spaces that not only improve the quality of physical and mental life of human beings, but they collaborate with the recovery of habitats for urban fauna and even promote pollination, which currently occupies environmentalists and that can be solved through the implementation of policies that promote the use of green infrastructure, which has begun to be seen in some cities such as Toronto, Sydney, Copenhagen, and others around the world where there are action plans to preserve it.

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