Urban Heat Islands: Green Roofs as a Potential Way to Attenuate Temperatures in Cities

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***Abstract*— The excessive construction and the destruction of green spaces have had notable consequences on the environment within cities. Under this context, green roofs have been proposed to attenuate these issues and to achieve sustainable building practices. In this paper, technical and construction aspects of green roofs are used to classify different systems. By reviewing the benefits related to the mitigation of the urban heat island effect, reduction in building energy consumption, improvement of air pollution, water management and increase in sound insulation, among others, this paper shows how green roofs may contribute to more sustainable buildings and cities. It is expected that this paper may not only propose a solution, but it may also raise awareness of the importance of urban greenery.**

***Keywords:* sustainable construction, urban greenery, urban heat islands, green roofs**

***Resumen*— La construcción excesiva y la destrucción de espacios verdes han tenido consecuencias notables en el medioambiente dentro de las ciudades. En este contexto, los techos verdes han sido propuestos para atenuar estos problemas y lograr edificios sostenibles. En este artículo, se utilizan aspectos técnicos y constructivos de los techos verdes para clasificar diferentes sistemas. Al examinar los beneficios relacionados con la mitigación del efecto isla de calor urbano, la reducción del consumo de energía de los edificios, la mejora de la contaminación del aire, la gestión del agua y el aumento del aislamiento acústico, entre otros, este documento muestra cómo los techos verdes pueden contribuir a que los edificios y las ciudades sean más sostenibles. Se espera que este documento no sólo pueda proponer una solución, sino también generar conciencia sobre la importancia del verdor urbano.**

***Palabras clave*: construcción sostenible, verdor urbano, islas de calor urbanas, techos verdes**

I. Introduction

Green spaces add to the provision of ecosystem services in urban areas. Urban greenery encompasses parks, squares, street trees and private gardens, and it comprehends a significant aspect of all cities. They allow us to mitigate harmful effects of environmental pollution by promoting air sanitation, cooling temperatures, retaining precipitation and attenuating noise by its sound absorption capacity.

Throughout the years and exacerbated by the populations' growth, cities have increased the construction of buildings and streets to satisfy the citizens' needs. This way, green spaces have been reduced and displaced, and with them the benefits they contribute. If this growth were to occur without fundamentally addressing the climate impacts of intensified urban development and global warming, many cities would become much hotter and less liveable.

The United Nations 2030 Agenda and its Sustainable Development Goals (SDGs) have developed the path to stop and mitigate this heating process that is taking place in many urban areas of the world. More specifically, there are two SDGs that refer to this issue. First, SDG #11 centers around making cities and human settlements inclusive, safe, and sustainable [1]. The second, but not least important, is SDG #13 that looks forward to taking urgent action to combat climate change and its impacts [1].

The purpose of this paper is to develop a sustainable city model, reincorporating the green spaces that have been displaced, aiming to mitigate the effects of global warming. To do so, a description of the problem and its causes will be introduced, as a way of presenting the current concerns and worries that excessive construction and the elimination of green spaces bring with it. This will be followed by the presentation of green roofs, used as a construction method that incorporates greenery in its structure. In the last section, an evaluation of the effectiveness of this proposal will be introduced. It is expected that this paper may not only propose a solution, but it may also raise awareness of the importance of urban greenery.

II. Problem Description: Urban Heat Island Effects

Due to the overpopulation and the consequent housing emergency, construction companies are supplanting the much-needed vegetated surfaces with more and more buildings and roads made of low-albedo materials. The term "albedo" is described as the relative amount (ratio) of light that a surface reflects compared to the total incoming sunlight. A surface with a high albedo will reflect more sunlight than a surface with low albedo [2, first section]. Therefore, low-albedo materials that are used for constructing high density buildings are one of the major causes of increasing temperatures in the urban environment known as Urban Heat Island (UHI) effect.

The increase in waterproof surfaces, excess heat from residential buildings, industry and traffic are among the other causes of the Urban Heat Island effect. National Geographic's encyclopedic entry defines the UHI as a metropolitan area that is a lot warmer than the rural areas surrounding it [3, article section]. This is the reason it is theoretically considered an "island".

The temperature rise carries a variety of consequences that affect many aspects of an individual's life. According to [4, p.2] some of them are:

- Increase in the electricity consumption, due to the need of regulating the temperature inside the buildings in benefit of the owner's comfort. Here, a vicious circle begins to generate, where due to the increase in temperatures, the necessity of air conditioning increases as well, and air conditioning systems in turn promote the formation of UHI.

- Reinforcement of climate change, because the increase in the electricity consumption adds to the atmospheric pollution and the greenhouse gas emissions. High temperatures are an environment hospitable to photochemical reactions in the atmosphere and the formation of smog and tropospheric ozone, which in high concentrations causes damage to health human and biodiversity.
- Impact on water quality, because the transfer of excess of heat accumulated in rainwater produces hot currents that are dumped into streams and rivers. It can also be harmful to the health of the ecosystem.
- Deterioration of human health, since heat waves generate discomfort, breathing difficulties, exhaustion, and even cardiac arrests. These high temperatures also generate certain conditions that, combined with other factors such as poor hygiene and water storage, cause an increased risk of diseases such as dengue, due to the expansion of populations of the transmitting mosquito.

These challenges that affect multiple aspects of humans' life can be enhanced. Several projects have been developed that seek to improve the quality of life within cities, taking them towards a sustainable and environmentally friendly future.

III. Green roofs as an innovative and environmentally friendly solution

The lack of green spaces in highly urbanized zones increases the congestion and pollution daily and contributes to the formation of the urban heat islands and, consequently, their impacts on citizen's life. Therefore, the incorporation of urban greenery is proven to mitigate UHI effects.

An innovative and less conventional way to integrate spaces for growing greenery are green roofs. As described in [5, p.5], a green roof shall be understood as a building system with a plant finish on a bed of soil or substrate that is specially designed for obtaining environmental benefits. The plant cover may be total or partial and it does not refer to terrace roofs with potted plants but to building technologies for improving the habitat or saving energy consumption, i.e. technologies that fulfil an ecological function.

When thinking about installing a green roof, certain concepts must be taken into account. These are related to the users' goals, the type of green roof that is wanted to be installed and the structure available to do so.

A. Types of Green Roofs

Green roofs can be classified according to either the type of plants desired to place, because of the different volume and layers of dirt each one requires, or the structure in which it will be located. There are different options which might be used as suggested by [6, p.6].

1)Type 1 – Extensive Green Roof: this type of roof is recommended for building structures with limited load bearing capacity and in areas with no or minimal regularity of use. It provides a meadow effect, which requires only low maintenance as shown in [6, Fig.3].

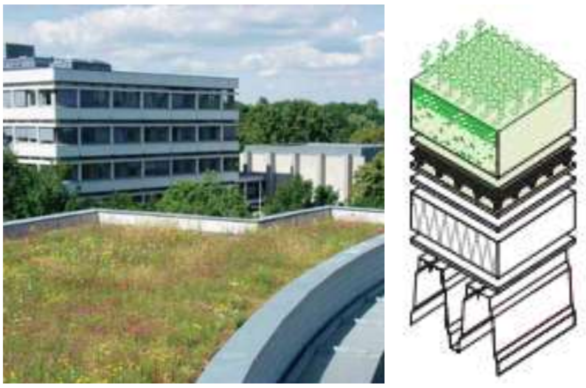

Fig. 3. Composition of an Extensive Green Roof [6].

2)Type 2 – Semi Intensive Green Roof: it is used where there is the desire to create a pleasant environment that can be used by those working or living at the location. This roof is ideal for the creation of an outdoor living space. This garden roof system utilizes basic plant types, which require more maintenance than the extensive roof. Fig.4 [6] shows an example of this type of green roof.

Fig. 4. Composition of a Semi Intensive Green Roof [6].

3)Type 3 – Intensive Green Roof: as shown in [6, Fig.5], this system is designed as a landscaped roof garden which may include an irrigation system. It opens practically all the possibilities of normal ground-level gardening and it is ideal where a suitable strong board bearing structure is available.

Fig. 5. Composition of an Intensive Green Roof [6].

4)Type 4 – Ground Level Green Roof: it is used in circumstances where substantial planting is realized using heavy mechanical plant and equipment during construction. It is considered suitable for ground level structures such as underground car parks as seen in [6, Fig.6].

Fig. 6. Composition of a Ground Level Green Roof [6].

B. Layers of a Green Roof

Every green roof must have a good composition of layers of suitable materials that provide it with a proper structure. This is to withstand vegetation loads and to protect the building below from plant roots and from water and humidity seepage. Although there are various layer options, they all fulfil this same function. Next, a typical build-up of a green roof model will be described, extracted from the "Stormwater Management Guidebook" [7, p.62].

1)Plan Cover: The type of plants used depends on whether a low maintenance extensive green roof is chosen or an intensive one with the more formal features expected from gardens. The former is limited to succulents, grasses and herbs, while the latter can be planted in accordance with the wishes of the gardener.

2)Substrate: The depth of growing media to use depends on whether the roof is the extensive or the intensive type. Soil depth can start from 40 mm upwards. The content and ratio of organic and mineral material in the mixture depends on the types of plants used.

3)Root-Permeable Filter Fabric: A semi-permeable needled polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it. The filter fabric must not impede the downward migration of water into the drainage layer.

4)Drainage Layer and Drainage System: A drainage layer is placed between the root barrier and the growing media to quickly remove excess water from the vegetation root zone. The selection and thickness of the drainage layer type is an important design decision that is governed by the desired stormwater storage capacity, the required conveyance capacity, and the structural capacity of the rooftop. The effective depth of the drainage layer is generally 0.25–1.5 inches thick for extensive green roof system and increases for intensive designs.

5)Protection Layer: This sheet is for the mechanical protection of the water insulating layer during construction work. It retains moisture and allows roots to grow through, thus enhancing cohesion of the layers above.

6)Root Barrier: Another layer of a green roof system is a root barrier that protects the waterproofing membrane or insulation layer from root penetration.

7)Waterproofing Layer: All green roof systems must include an effective and reliable waterproofing layer to prevent water damage through the deck layer. A wide range of waterproofing materials can be used, including hot applied rubberized asphalt, built up bitumen, modified bitumen, thermoplastic membranes, polyvinyl chloride (PVC), thermoplastic olefin membrane (TPO), and elastomeric membranes (EPDM).

8)Deck Layer: The roof deck layer is the foundation of a green roof. It may be composed of concrete, wood, metal, plastic, gypsum, or a composite material. The type of deck material determines the strength, load bearing capacity, longevity, and potential need for insulation in the green roof system.

The different layers that make up a green roof are shown in [5, Fig. 7]. They are presented following the order previously stated.

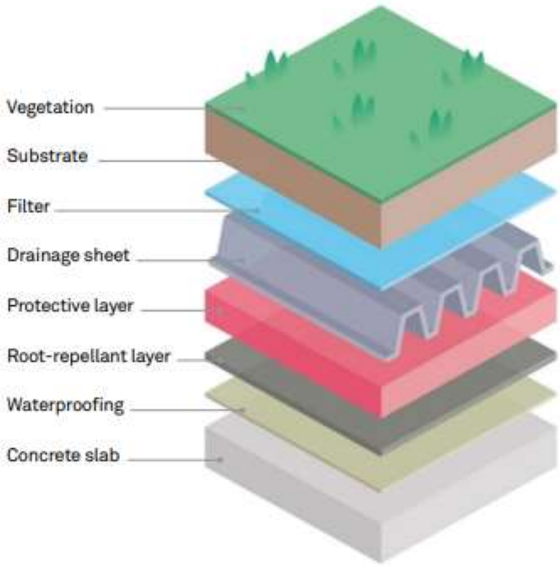

Fig. 7. Layers of a Green Roof [5].

In some areas, it is highly recommended for green roofs to use an automated irrigation system. This includes additional installation work. The location of the pipes will have to be borne in mind during maintenance operations so they can be treated with care and protected from any damage [5, p.33].

C. Green Roofs in Existing Buildings

Existing buildings require the roof design to be studied so it meets the requisite load conditions. Some existing buildings have sufficient capacity, but in any case, a structural engineer must check in advance the weight that the structure can hold, to ensure the building's safety [5, p.13].

Green roofs can be installed on a wide range of roofs, including those with shaded areas, roofs with low load-bearing capacity, roofs on high-rise buildings, with limited access, and even on sloping roofs. The latter must not have a slope over 45 degrees, as stated in [5, p.12]. Otherwise, technical conditions of vertical gardens must be adopted, to ensure the stability of the drainage systems, the substrate and the vegetation.

An important aspect to keep in mind is that green roofs must be maintained. The frequency and grueling process of this maintenance vary depending on the chosen green roof, according to the types of green roof described previously in this paper.

IV. Positive aspects of green roofs

Thanks to the ecological and economic advantages, and free space they offer, green roofs are beneficial for people and the environment. In the same way, they help to improve the life expectancy of buildings and their energy balance.

One of the main ecological advantages that comes with green roofs is, as expected, the reduction in the UHI effect. This is achieved through the process of transpiration and humidification of dry air, which improves the climate and increases people's sense of well-being [5, p.8].

Another aspect that they have in improving people's health is the optimization of air quality through vegetation. It has been demonstrated that it is effective in reducing atmospheric pollution thanks to its capacity for filtering particles and absorbing pollutant gases.

These vegetated surfaces also act as a storage tank for rainwater. Rainwater can be reused, through cistern technology, for irrigating the roof itself or put to other uses such as cleaning or cooling appliances. They prevent local floods, as the rainwater that goes directly to the sewerage system can be reduced by between 50% and 90%, depending on the chosen green roof [5, p.8].

As to buildings, a green roof provides extra layers of insulation. A hydraulic insulation is achieved because both the vegetation and the substrate protect the waterproofing membrane by alleviating the effects of temperature fluctuations. There is also an acoustic insulation improvement. A green roof reduces the reflection of sound by up to 3 dB and improves acoustic insulation by up to 8 dB [8, p.5].

However, one of the most important building benefits of green roofs is their thermal insulation properties. This additional insulation reduces temperature transfers between the inside and outside of buildings. They reduce excessive heat during the summer and minimize heat losses in the building during the winter, cutting heating and cooling costs. This statement is adequately illustrated in [4, Fig. 8]. It shows a green roof built over the City Hall of Chicago (U.S.A.) and the effects it has on the surface's temperature, demonstrating a difference of 40 degrees compared to conventional materials.

Fig. 8. Example of temperature differences between a green roof and a conventional roof [4].

As indicated by a report of the United States General Services Administration, green roofs can also contribute to roof longevity [8, p.5]. Properly installed green roofs more than double the number of years typically needed before a roof must be replaced, as compared with conventional and white roofs.

All these benefits are considered a fundamental development for cities and allow green roofs to have a positive projection for the future. In addition, there is sufficient information to carry out works that include this constructive innovation in their projects.

Although there are many positive aspects, it is also important to inform that green roofs may present some disadvantages. As stated in [8, p.3], the main design, installation and management challenges of green roofs include:

- Assurance that the building can support a green roof.
- Quality installation and leak prevention.
- Maintenance requirements.
- Potential plant loss due to environmental conditions or mismanagement, among other items.

Despite these issues, many involved citizens have been trying to implement green roofs on their urban landscapes. Although not all of them have achieved it, persistence and perseverance in spreading this proposal have been of great importance to achieve a change. As explained by Tim Cousin, one of the founders of the Roofscapes team in Paris: "To have any meaningful impact on the city you must have a lot of roof terraces, but we have seen an evolution of the mentality around this issue. A few years ago, people weren't interested in climate change, now they've realized it's urgent" [9, paragraph 18].

V. Conclusion

In this paper, a critical view of the constructive development of cities and the negative effects this has on the environment has been provided. Green roofs are presented as an important innovation in the construction world that not only have both aesthetic and functional benefits, but they also become a tool to combat climate change and its consequences. By means of this approach, citizens and urban planners have a better alternative with compelling positive impacts for sustainable urban development.

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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