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The urban green index focused on the design of green roofs integrated into the urban area of Guayaquil

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***Abstract*—**The urban green index of the city of Guayaquil is one of the lowest in Latin America, bordering on 2.54 m2 per inhabitant, which is far from the minimum recommended by the WHO of 9m2 per inhabitant, which significantly affects air conditions and quality. of general life of an integral society. This scarcity of vegetation is a product of the rise of commercial and informal development in the city, which only has urban green areas on main avenues or streets. The objective of this scientific article is to increase the urban green index by integrating green roof models in buildings in the urban area of Guayaquil, thus configuring an interconnected network of green roofs that rethinks the urban design of the city. Two types of methodology are used, qualitative based on the study of urban regulations and a green infrastructure approach georeferenced in ArcGIS to obtain percentages and quantitative data for the identification and proposal of new urban green areas in the city of Guayaquil. In conclusion, it is obtained that by proposing a green roof for every ten buildings in the urban area of Guayaquil, the concentrated green index can be raised to up to 5.54 m2 per inhabitant, which would be closely aligned with the minimum allowed by the WHO of 9m2 per inhabitant.

Keywords: Urban area, sustainability, quality of life.

INTRODUCTION

The lack of trees and green spaces in Guayaquil is alarming and irrational due to its multi-diverse conditions and subtropical climate. Guayaquil has approximately 66,000 trees (not counting forests) when it should have 500,000, according to environmental experts in Guayaquil (Guardiola and García-Quero, 2014). "The deficiency is serious," according to architect Elvira Plaza, who points out that it is a city that grew against its natural environment.

The Urban Green Index is proposed as a guideline to measure the quality of life and health of residents. This can change the perspective of cities that do not consider the environment in their growth or urban development, which is particularly relevant in the city of Guayaquil.

As a predominant factor worldwide, globalization has influenced the constant generation of green areas within dense, commercial, industrial, or development hubs of large cities. This calls into question the urban habitability of people in public spaces, leaving the concept of green infrastructure without space within the gray area that entails the paradigm of the world's most developed cities (Mao et al., 2024).

In Latin America, development follows this unsustainable model for the territory. Instead, it occurs through the illegal or informal appropriation of protected green areas, or green spaces such as trees, shrubs, and natural gardens, which has led to the depletion of green spaces within the city environment (Mao et al., 2024). Aspects such as these generate resource degradation and risk from natural phenomena due to the lack of protection generated by artificial landscape elements such as buildings.

Buildings as singular entities seem to have a parasitic relationship with the landscape. Sustainable architecture often strives to be more than a "cosmetic" process for "green" cities. An emerging field of research called "biodesign" offers opportunities to find efficient ways for cities to "grow." Tools and technologies allow architects to draw inspiration beyond the beauty of nature, from its resilient functions and processes. The discoveries of this emerging field are so powerful that they change the way we conceptualize a symbiotic relationship between the built and the cultivated, aiming to be an organic system that coexists and generates implicit harmony (Petschek et al., 2024).

The city as an organism is a frontier that is no longer utopian in cities like Singapore, where the built environment can be viewed as an organism mutually dependent on the natural world. Buildings that were once barriers to the environment can become an integral part of the natural landscape, like a living organism.

An organism metabolizes at many scales, from cells and organs to bodies and ecologies. Cities also thrive on multiple structural levels, where material composition has as much impact on the urban landscape as transportation networks. The built environment drives the evolution of ecologies, as they need to constantly adapt to humans, not the other way around. Biointegrated cities must engage other organisms and respond at different scales, co-creating sustainable ecologies with nature.

This concept is adopted through natural elements embedded in the building, including vertical gardens, urban gardens, and green roofs. These latter have great potential for coverage and the generation of new public spaces for buildings such as offices or government buildings that can generate resilient spaces within them, as envisioned by the approach to urban organisms or the city as an organism.

Green roofs can reduce heat by reflecting solar radiation and providing shade, a common characteristic of Guayaquil's subtropical climate, which generates an average relative humidity of 65 to 85%. This impacts on the conditions for users who travel through the city center. Another benefit related to relative humidity is the reduction of heat through the process of transpiration, which lowers the temperature inside and outside the building, which in turn improves air quality by removing pollutants and trapping particles on its leaves. Thus, green roofs are gaining increasing recognition as a modern and environmentally friendly technology to address climate change and the most common environmental problems in urban environments.

MATERIALS AND METHODS

a. CONCEPTUAL SCHEME OF GREEN ROOFS

Green roofs have multiple benefits and are a wonderful resource for combating the consequences of climate change. Green roofs could also reduce a large percentage of flooding. As they are implemented, we will have a lower vulnerability of the city to flooding due to precipitation. Furthermore, they generate efficient cooling in buildings through techniques such as passive design and the use of appropriate materials. This not only helps reduce air conditioning consumption but also contributes to reducing energy demand and associated carbon emissions (Chen et al., 2021; Rotondo et al., 2022).

Furthermore, reducing the urban heat island is crucial to improving the quality of life in cities. This phenomenon occurs when urban areas experience higher temperatures than surrounding areas due to the slow absorption and release of heat by urban materials such as asphalt and concrete (Rotondo et al., 2022). By implementing urban design strategies that favor vegetation, green spaces, and materials that reflect more solar radiation, this effect can be mitigated, thereby improving the thermal comfort and health of urban residents.

Both efficient building cooling and reducing urban heat islands are important aspects for encouraging cities to become more sustainable and suitable for long-term habitability.

In European countries such as France, Switzerland, and Germany, these systems have been implemented since the 1980s and have achieved significant results, such as reducing carbon dioxide and improving air quality.

Green roofs are recognized as contributing to the energy efficiency of buildings. Given that rooftops represent between 20 and 25% of all urban areas, an environmentally friendly system of this type can provide a sustainable solution for reducing energy consumption.

Green roofs have a positive effect on human well-being, benefiting residents; they also act as microhabitats for insects, generating oxygen and reducing CO2 levels.

The vegetation layer on green roofs varies depending on the type of construction. For example, on extensive green roofs with a limited substrate thickness, plants such as herbs, succulents, and grasses typically bear fruit. There are small variations in substrate thickness that can significantly affect plant development (Heim & Lundholm, 2022) observed that species of the genus Sedum prevailed in thinner substrates (~5 cm), while at greater depths (~15 cm) they were necessary for the grasses to maintain their persistence.

The substrate is the primary element for the development of green roofs, functioning as a physical support and source of water and nutrients for vegetation. The substrate must allow for good development and penetration of roots and other buried plant parts; it must be structurally sound, capable of accumulating water and delivering it to plants, and allow for adequate gas diffusion. The substrate for extensive roofs must have high structural stability, good support, minimal organic content, low bulk density, high water retention capacity, high air porosity, high hydraulic conductivity, high sorption capacity, and low leaching.

Different components (organic and inorganic fractions) are constantly mixed to achieve an intermediate result appropriate for the building's function (Zhong et al., 2024). The purpose of the filter layer is to prevent the passage of fine material from the substrate into the drainage system, which could lead to drainage problems, in addition to the loss of part of the substrate, which could drastically affect the vegetation growing on it. For the manufacture of fine, lightweight filters, materials such as polymeric fibers or polyolefins are used, which are typically connected to the drainage layer to speed up installation.

The purpose of the drainage layer is to ensure a balance between the water and air content throughout the structure (Liang et al., 2024). The drainage layer allows excess water to drain away during rainfall and irrigation, preventing weight gain for the structure and providing the air space necessary for proper root oxygenation. They typically consist of hollow-core panels made of polyethylene or polystyrene, or layers composed of porous granular materials such as expanded clay or slate, pumice, natural pozzolan, among others. The material and thickness of the drainage layer can vary depending on the type of green roof and climatic conditions (Yaipimol et al., 2022). Lightweight, thin materials such as polyethylene and polypropylene are more suitable for expandable green roofs due to their weight restrictions. The thickness of this layer can vary between 1 and 1.5 cm. In intensive green roofs, the drainage layer can be heavier (usually composed of pebbles) and its thickness can be 4 cm or more. The water protection and retention layer provide mechanical protection to the lower layers as well as preventing moisture from reaching the base of the construction (Peng et al., 2023).

It is usually made of polypropylene or polyester geotextile. Sometimes, this layer is fused with an impermeable membrane and a root-proof layer, combining all of their functions. Root barrier and impermeable layer. The function of the root barrier and impermeable layer is to safeguard the building from the action of roots and water (Shcherbak et al., 2024). The latter are generally made of asphalt or polyvinyl chloride (PVC) and reinforced with polyester, fiberglass, and mineral granules. They can also be composed of synthetic rubber or polyethylene. The root-resistant material can be included in the impermeable membrane or arranged as a separate layer on top of it. They can constitute a physical barrier (thin layers of polyethylene or low-density polyethylene, 0.05 cm thick) or a chemical barrier (materials impregnated with chemical compounds, e.g., copper, that inhibit root development) (Yarlovska and Mondeshka, 2023).

b. METHODOLOGY

It is developed under a mixed-use study approach framed within the peri-urban structure of Guayaquil. Through site visits, we will document public space patterns and green area deficits, compiling a collection of the necessary data to define a proposal for interconnecting green roofs through a floating spatial structure.

The essential aspects to be considered in the distribution of green roofs will be mapped and categorized according to the building's function. Based on these patterns, a design will be proposed that seeks to optimize the urban development of buildings in height to reduce the climatic impact during operating hours. These factors are characterized by intense sunlight, which generates a redistribution of the climate spectrum based on how the green roofs interconnect and affect the ground level. Therefore, field evaluation samples will be taken to determine the current state in degrees Celsius and the change generated by the green roofs after their configuration modeled in a 3D simulation (Macas-Espinosa et al., 2021).

Specific data will be considered, including an analysis of urban density, and design strategies will be proposed to promote the accessible inclusion of each green area. Analyzed as an area with high thermal influence from 12 noon to 5 p.m., the Mapasingue sector is located. This is a peri-urban area with high residential and commercial development connected to Guayaquil via its Juan Tanca Marengo collector road, known for its unique combination of formal and informal human settlements, services, and businesses clustered around the road and commercial locations. This area, strategically close to Guayaquil's service and macro-commercial district, generates severe heat islands where the action plan will operate based on the trend of heat islands in public spaces such as parks, vacant lots, and homes.

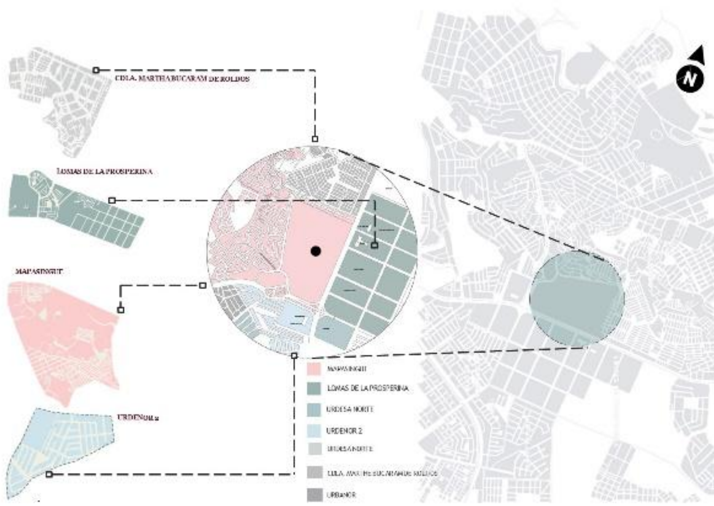

Fig. 1. Urban structure of the study area. Note: Prepared by the authors.

As part of the urban planning process for developing the proposal, the action plan was characterized by two subplans that generate a proposal that interconnects the design of green roofs and materials to articulate urban areas and impacts the climate comfort of the area.

Table 1. Green Roof Action Plan

Axis	Preparation	Diagnostic Analysis	Prioritization	Action Plan	Subplans
Recovery of public space and green areas through the design of green roofs	Implement a program that integrates green areas within empty lots and public spaces	Development of floating public spaces as green corridors	Interconnect public space and green areas through green roofs	Interconnected green roof plan	Green areas plan Public space recovery plan

Note: Prepared by the authors.

RESULTS

a. QUALITATIVE/QUANTITATIVE THERMAL ANALYSIS

In the study area, which covers a radius of 2 kilometers, a trend of heat island coverage is observed, generating patterns in open areas such as vacant lots that tend to generate fires and high solar impact, reflecting the thermal dynamics of the area. To categorize the land, a Pantone color was generated with trends in these two predominant patterns, ranging from gray for high solar intensity to salmon tones for low intensity, identifying land uses for green areas, public spaces, and housing.

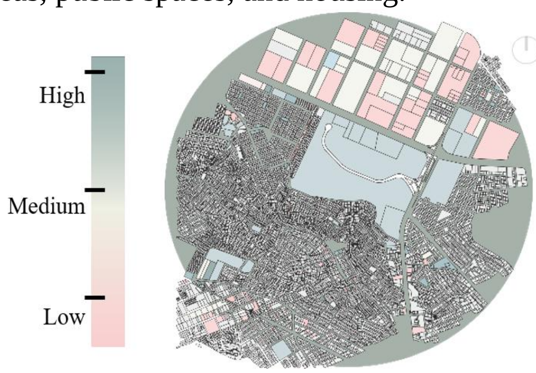

Fig. 2. Thermal analysis of the study area. Note: Prepared by the authors.

The study sector was analyzed using a mixed-approach methodology that, as an action plan, characterized the important indicators of the territory with potential design strategies. The first qualitative-quantitative analysis polygon reveals the urban structure of the area. This approach allowed prioritizing the plan's strategic framework; five specific concepts for the interconnection of public spaces through green roofs. To characterize the sustainability indicators, the strategy prioritization method was used through a mixed analysis of each variable corresponding to the development of the green roof plan.

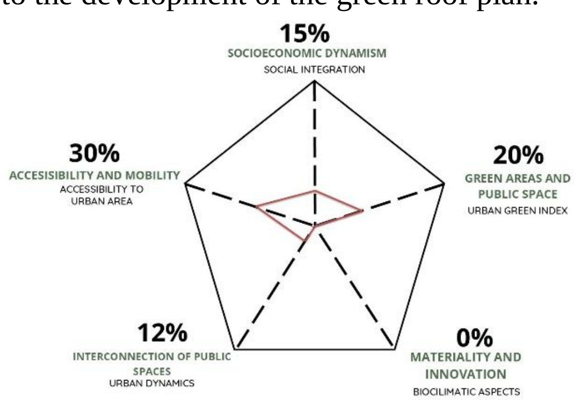

Fig. 3. Qualitative/quantitative polygon of the study area. Note: Prepared by the authors.

Discussion

The action plan proposes placing a network of interconnected green areas in direct categories (red line) and indirect categories (blue line), as they will offer multiple benefits to urban communities, contributing to the development of each deficient indicator of the territory. These spaces will promote climate comfort and increase the dynamism of the surrounding social and economic spectrum by reducing pollution and increasing the value of nearby properties. Furthermore, they will facilitate social cohesion by serving as meeting points, support biodiversity, enrich cultural life with recreational and educational activities, and reduce urban noise, creating a more pleasant and comfortable environment.

The inclusion of green areas in both homes and public spaces is based on the analysis of heat island dynamics as a factor in the climatic functionality of both the interior and exterior. A green courtyard with street furniture will be created inside, providing a space for recreation and relaxation. Outside, green areas will be strategically distributed, some of which will serve as vehicle routes, improving the functionality and aesthetics of the environment.

Fig. 4. Green roof and public spaces interconnection scheme. Note: Prepared by the authors.

Conclusion

The development of green roofs based on their location will improve the urban green index of the sector by up to 20% of the urban green area. The existing index increased by 60%, from 6.02 m2/inhabitant to 9.63 m2/inhabitant. This is a progressive proposal thanks to the fact that the internal and external interconnections (blue and red lines) can be converted into new green corridors, increasing the climate comfort of the sector.

As part of the additional benefits, according to climate comfort simulation sampling, noise emission levels have decreased by up to 20 decibels in the housing sector. Overall, the use of green roofs in Guayaquil supports environmental sustainability, improves urban resilience, and contributes to improving the quality of urban life. As the study area continues to develop, green roofs could play a pivotal role in creating new connections for public spaces within ecological corridors, denoting new avenues for urban development while simultaneously providing ecological and social benefits.

REFERENCES

Chen, C., Yang, X., Wen, Q., & Zhang, Y. (2021). Ecological evaluation of forest wellness - Taking Qinyuan County of Shanxi as an example. Volume 675, Issue 1, 675(1), 2020. https://doi.org/10.1088/1755-1315/675/1/012009

Guardiola, J., & García-Quero, F. (2014). Buen Vivir (living well) in Ecuador: Community and environmental satisfaction without household material prosperity? Ecological Economics, 107, 177–184. https://doi.org/10.1016/J.ECOLECON.2014.07.032

Heim, A., & Lundholm, J. (2022). Functional trait database for Nova Scotian coastal barren, green roof, and ruderal flora. Ecology, 103(6), e3678. https://doi.org/10.1002/ecy.3678

Liang, H., Shen, J., Yip, H. L., Fang, M. M., & Dong, L. (2024). Unleashing the green potential: Assessing Hong Kong's building solar PV capacity. Volume 369, 369. https://doi.org/10.1016/j.apenergy.2024.123567

Macas-Espinosa, V., Vera-Rodríguez, L., & Barzola-Monteses, J. (2021). Analysis and Evaluation of Energy Efficiency in Buildings Based on Building Information Modeling. Pages 137 - 149, Online. https://doi.org/10.1007/978-3-030-97862-4_10

Mao, Y., Li, Y., Bai, X., Yang, X., Han, Y., & Fu, X. (2024). Scenario-Based Green Infrastructure Installations for Building Urban Stormwater Resilience—A Case Study of Fengxi New City, China. Volume 16, Issue 10, 16(10). https://doi.org/10.3390/su16103990

Peng, W., Yuchi, X., Sun, Y., & Shan, Z. (2023). The Spatial Protection and Governance of Territories Based on the Ecological Product Supply: A Case Study in Beijing–Tianjin–Hebei, China. Land, 12(12), 2130. https://doi.org/10.3390/land12122130

Petschek, P., Aung, A. P. P., Suwanarit, A., & Irvine, K. N. (2024). Integration of Building Information Modeling and Stormwater Runoff Modeling: Enhancing Design Tools for Nature-Based Solutions in Sustainable Landscapes. Volume 16, Issue 9, 16(9). https://doi.org/10.3390/su16093694

Rotondo, F., Perchinunno, P., L'Abbate, S., & Mongelli, L. (2022). Ecological transition and sustainable development: integrated statistical indicators to support public policies. Volume 12, Issue 1, 12(1). https://doi.org/10.1038/s41598-022-23085-0

Shcherbak, V. G., Danko, Y. I., Tereshchenko, S., Nifatova, O., Dehtiar, N., Stepanova, O., & Yatsenko, V. (2024). Circular economy and inclusion as effective tools to prevent ecological threats in rural areas during military operations. Global Journal of Environmental Science and Management, 10(3), 969–986. https://doi.org/10.22034/gjesm.2024.03.03

Yaipimol, E., Vaiseesang, T., Surinseng, V., Charoenlertthanakit, N., Wanitchayapaisit, C., & Suppakittpaisarn, P. (2022). Potential human well-being benefits from ecological infrastructure: a case study from Chiang Mai, Thailand. Acta Horticulturae, 1356, 417–425. https://doi.org/10.17660/ActaHortic.2022.1356.51

Yarlovska, N., & Mondeshka, M. (2023). USE OF ECOSYSTEM SERVICE ASSESSMENTS FOR SUSTAINABLE SPATIAL PLANNING PURPOSES. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM, 23(5), 295–302. https://doi.org/10.5593/sgem2023/5.1/s20.37

Zhong, W., Schröder, T., & Bekkering, J. (2024). Implementing biophilic design in architecture through three-dimensional green spaces: Guidelines for building technologies, plant selection, and maintenance. Volume 92, 92. https://doi.org/10.1016/j.jobe.2024.109648