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Vertical Gardening: A Pathway to Sustainable and Biophilic Urban Environments

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ABSTRACT

This paper evaluates vertical gardening as a potential solution to critical urban challenges such as climate change and food scarcity. It explores how vertical gardens can improve air quality, enhance energy efficiency, optimize the use of limited soil, and provide aesthetic benefits. This research highlights the contrasting outcomes of Singapore and Mexico City, which suggest that while vertical gardens offer significant advantages, their success heavily depends on technological and design factors, long-term government support, and meticulous management. Overall, it concludes that strategic planning and policy-making are needed to realize the complex goals of vertical gardening.

Introduction

In the modern era, humanity finds itself at a crossroads, facing a multitude of pressing environmental challenges that jeopardize the well-being of present and future generations. From extreme weather events to rapid urbanization, from resource depletion to escalating pollution levels, the threats to our planet and its inhabitants are manifold and urgent. Compounding these challenges is the exponential growth of the global population, exacerbating the strain on Earth's finite resources. As the Global Footprint Network has starkly reminded us, sustaining humanity's current pace of resource consumption would require 1.75 Earths. Amidst this depletion of resources, the quest for habitable spaces assumes paramount importance. Designing cities fit for the 21st century demands solutions that not only meet the needs of their inhabitants but also address pressing environmental concerns. It is imperative to transform our urban landscapes into sustainable havens that foster a deep connection with nature—a concept known as biophilia.

The integration of biophilic elements into urban environments presents a promising avenue for achieving this balance. Among the myriad strategies available, vertical gardening emerges as a compelling solution. Vertical gardens, also known as green walls or living walls, offer a multifaceted approach to urban sustainability. These living, breathing installations not only enhance the aesthetic appeal of urban spaces but also provide a host of environmental benefits, from mitigating air pollution to regulating temperature and fostering biodiversity.

This research discusses the intricate relationship between vertical gardening and the creation of sustainable, biophilic cities. By examining the efficacy of vertical gardening as a solution to some of the exigent urban challenges, this study seeks to evaluate the potential of biophilia in shaping the cities of tomorrow. Through an interdisciplinary approach encompassing environmental science, urban planning, and biophilic design principles, this work aims to elucidate the transformative potential of vertical gardens in redefining urban landscapes.

Concepts of Vertical Gardening

Vertical gardens, also known as living green walls, involve planting plants on walls or the exterior surfaces of buildings rather than traditional ground planting ("What are Vertical Gardens?", n.d.) As urbanization encroaches upon available land, vertical gardens have garnered attention for their ability to utilize vertical space in densely populated areas (Stollberg & von Birgelen, 2023, p.1). These gardens serve multiple functions, including potentially blocking or mitigating sunlight that affects building temperatures and purifying the surrounding air.

However, establishing and maintaining a vertical garden is a complex endeavor. Various factors influence their success, including the design of the vertical garden system, choice of growing containers, irrigation methods, plant selection, and growing media (Rameshkumar, 1970, p.1).

Moreover, vertical gardens demand meticulous upkeep beyond initial setup due to their distinct environmental conditions compared to ground-based plants, which draw nutrients from the soil. Technological advancements, such as Internet of Things (IoT) systems, have emerged to optimize the environment for plants thriving on building exteriors. IoT systems not only gather data on temperature, light intensity, humidity levels, and plant growth but also utilize this information to adjust variables such as nutrient supply and water distribution via automatic irrigation systems (Halgamuge et al., 2021, p.2).

Benefits of Vertical Gardening and The Connection Between Vertical Gardens and Sustainable Biophilic City

Air Quality

Plants can mitigate indoor air pollutants, making indoor vertical gardens valuable tools for air purification within buildings. Harmful volatile organic compounds (VOCs), such as benzene, significantly degrade air quality and can lead to severe health issues. (Ulker et al., 2021, p.1) However, vertical gardens outfitted with plants have been shown to reduce CO_2 and VOC levels by approximately 25 percent and 80 percent, respectively. (Tai, 2015) Moreover, a study conducted by the University of Technology Sydney (UTS) and Ambius revealed that indoor vertical gardens are capable of eliminating an impressive 97 percent of hazardous substances from the surrounding air within just eight hours. (Miletic, 2023) The capacity of vertical gardens to enhance air quality extends beyond indoor environments. A study conducted within the Government Financial Platform of Quito, Ecuador in 2018 revealed that 497 square meters of outdoor vertical gardens effectively ameliorated air quality. These green spaces notably decreased levels of CO, SO_2, NO_2, PM2.5, and PM10. Particularly significant was the reduction in levels of PM2.5 and PM10, indicating the potential of outdoor vertical gardens to address fine dust concerns. However, a notable finding was a marked increase in O_3 levels attributed to "solar radiation and the presence of plant species emitting volatile organic compounds." This underscores the importance of various factors, including plant species selection, concentration, and size, in determining the efficacy of vertical gardens for air purification. Consequently, further research is warranted to ascertain optimal settings and plant combinations to maximize effectiveness.

Efficient Use of Space

In today's urban landscapes, available land for public parks or gardens is dwindling (Colding et al., 2020, p.1). Buildings and roads increasingly dominate major cities such as New York, Seoul, and Tokyo. While it's true that many major cities already boast parks and other green infrastructure, the quantity and extent of these green spaces are insufficient to transform the entire urban environment. Given that the space on which buildings stand cannot easily be converted into green areas, one promising solution is the implementation of vertical gardens. Erecting gardens on the exterior walls of buildings offers a viable alternative to utilizing valuable ground space. This approach not only enables the creation of greenery but also maximizes space efficiency, effectively integrating both architectural and natural elements. Consequently, individuals are afforded greater access to nature within their urban environment, bringing cities one step closer to the vision of a biophilic metropolis.

Effective Solution to Urban Heat Island Effect (UHI)

Vertical gardens serve as a natural cooling mechanism to mitigate the elevated temperatures characteristic of developed urban environments. By absorbing solar radiation, the plants installed in these gardens prevent their conversion into heat, thus counteracting temperature increases (Ksenzhek & Volkov, 1998, p.31). Consequently, the temperature of external walls is naturally reduced (Nicolini et al., 2022, p.1), offering a means to alleviate the urban heat island (UHI) effect without requiring ground space for conventional gardens.

Furthermore, the integration of vegetation into architectural design yields environmental and microclimatic benefits within the city (Ivanova et al., 2020, p.3). This symbiotic relationship between vegetation and architecture not only contributes to cooling the urban environment but also enhances overall environmental quality, illustrating the multifaceted advantages of incorporating greenery into urban structures.

Energy Efficiency

In addition to their natural cooling properties, vertical gardens play a crucial role in enhancing energy efficiency and reducing the demand for air conditioning. Acting as insulation for buildings, these green walls diminish the transfer of heat between indoor and outdoor environments. Consequently, they are anticipated to lessen the cooling and heating load during the summer and winter months, thereby aiding in the regulation of indoor temperatures (Go et al., 2022, p.635).

A thermal transmittance experiment conducted on public buildings in Gunsan, Jeollabuk-do, Korea, underscored the significant enhancement in the thermal performance of building exteriors afforded by vertical garden systems (Go et al., 2022, p.635). Reduced heat transmission within buildings can lead to decreased reliance on air conditioning, resulting in substantial energy savings and a subsequent reduction in greenhouse gas emissions.

While implementing solutions that entail comprehensive reform of city structures or reduction in building heights may pose challenges, vertical gardens offer a practical and effective means of curbing energy consumption and mitigating the urban heat island effect.

Biophilic Design and Aesthetic Benefits

Vertical gardens not only address the urban heat island effect and enhance energy efficiency but also serve as key catalysts in advancing the concept of the biophilic city. The installation of vertical gardens represents a pivotal step toward creating a city that prioritizes nature in its design, planning, and management, as advocated by Beatley (2011, p.45). By integrating vertical gardens into urban landscapes, cities can enhance aesthetics and promote the well-being of their residents.

While the impact of a single building with a vertical garden may seem modest, the cumulative effect of the widespread adoption of biophilic design principles can significantly enhance the overall quality of urban spaces. Embracing the biophilic city concept through initiatives such as vertical gardens signifies a transformative shift towards creating sustainable and livable environments where residents can reconnect with nature and enjoy a higher quality of life.

Agricultural Farming

Vertical farming, the practice of cultivating crops on vertical surfaces, holds promise in addressing challenges faced by traditional agriculture. However, implementing vertical farming in building exteriors in urban areas presents significant challenges, particularly in controlling artificial temperature, light, water, and humidity (Dupis, 2023). Agriculture contributes to issues such as climate change, deforestation, and soil degradation, while available spaces diminish due to urbanization. In response, innovative techniques like hydroponics have emerged as viable alternatives for vertical farming.

Hydroponics, a method that enables farming without soil by utilizing water-based nutrients, has gained traction as a key approach in vertical farming. This innovative technique overcomes the limitations of traditional soil-based agriculture, offering greater flexibility and efficiency in crop cultivation while minimizing environmental impact.

Thinking from Real Cases

Efforts to implement biophilic urban environments through vertical gardening have been underway in many cities worldwide, leaving behind both legacies and limitations.

Singapore serves as a representative example, illuminating the positive future of vertical gardening. Since issuing the Singapore Green Plan (SGP) in 1992, Singapore has undertaken diverse efforts to enhance urban sustainability, including the expansion of green areas (Hoong, 2002, p. 41). In 2008, amidst long-term planning and continuous initiatives to create an eco-friendly environment, Singapore even introduced mandatory green building regulations that integrate architecture with vegetation (Yuen, 2020).

This initiative was Singapore's response to the unique limitations of the tropical city-state with a high-density population, where over five million people reside within 700 square kilometers and heavily rely on air conditioning. Singapore's long-term planning and pragmatic implementation have yielded positive results in reducing carbon emissions across the city while achieving aesthetic goals that attract tourists and create pleasing urban environments (“Singapore's Initial National Communication,” 2000).

Additionally, Singapore's case sheds light on the potential of vertical gardens for food security. During the COVID-19 pandemic, Singapore's low-income families faced food insecurity as the city-state relied heavily on food imports, accounting for 90% of its food supply. However, by engineering vertical farming systems capable of recycling water and providing uniform sunlight to plants, Singapore demonstrated the possibility of achieving food security through urban farming, even within limited ground and groundwater resources. Singapore’s case, showcasing the successful long-term collaboration between government, engineering, and citizens, hints at the direction that the future of the vertical garden.

The Via Verde project in Mexico City, which was introduced in 2016 with the slogan of transforming the city’s grey into green, offers another perspective on the future of vertical gardening. Supported by the government, the Via Verde project involved the construction of vertical gardens on columns along the Periférico highway, aiming to generate sufficient oxygen, filter toxic gases, capture dust, and process heavy metals in this heavily car-dependent megacity (Perrone, 2022).

However, the project has faced criticism from environmental activists. Critics argue that it has not fully delivered on its environmental promises and that its positive outcomes are primarily aesthetic, attracting international attention. One of the project's shortcomings lies in its oversimplified approach to the air-purifying effects of plants. While plants can indeed mitigate air pollution through phytoremediation, converting carbon dioxide into oxygen, not all plants are capable of this. Succulents and other plants predominantly used in the Via Verde project are unfortunately not well-suited for phytoremediation. The Via Verde project’s shortcomings suggest that vertical gardens should not only focus on creating a green appearance but also approach challenges to be solved more comprehensively.

Conclusion

In conclusion, the implementation of vertical gardening holds significant potential for creating eco-friendly and sustainable urban conditions to combat climate challenges and pollution. While its benefits are evident, turning it into a viable and effective measure for promoting sustainable biophilic cities requires more than just enthusiasm. It demands forward-looking policies that prioritize environmental sustainability and resilience, coupled with robust scientific and technological support. Additionally, fostering collaboration among government, industry, academia, and local communities is crucial for ensuring the successful integration of vertical gardening into urban landscapes. By adopting a holistic approach that addresses the multifaceted challenges of urbanization, we can harness the full potential of vertical gardening to create healthier, greener, and more livable cities for generations to come.

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References

Beatley, T. (2011). *Biophilic cities: Integrating nature into urban design and planning*. Island Press.

Colding, J., Gren, Å., & Barthel, S. (2020). The incremental demise of Urban Green Spaces. *Land*, *9*(5), 162. https://doi.org/10.3390/land9050162

Dupuis, A. (2023, January 19). *Vertical farming: Everything you need to know*. Eden Green. https://www.edengreen.com/blog-collection/what-is-vertical-farming

Go, B., Park, J., & Hwang, T. (2022). Case study on green wall effectiveness in public building for heat wave reduction and building energy saving. *The Journal of Next-Generation Convergence Technology Association*, *6*(4), 632–640. https://doi.org/10.33097/jncta.2022.06.04.632

Halgamuge, M. N., Bojovschi, A., Fisher, P. M. J., Le, T. C., Adeloju, S., & Murphy, S. (2021). Internet of things and autonomous control for vertical cultivation walls towards Smart Food Growing: A Review. *Urban Forestry & Urban Greening*, *61*, 127094. https://doi.org/10.1016/j.ufug.2021.127094

Hoong, C. L. (2002). *The Singapore Green Plan 2012*. Ministry of the Environment.

Ivanova, N., Ganzha, O., & Podkovyrov, I. (2020). Basic methodology in construction of vertical gardening of a building. *Journal of Physics: Conference Series*, *1614*(1), 012034. https://doi.org/10.1088/1742-6596/1614/1/012034

Ksenzhek, O. S., & Volkov, A. G. (1998). Fluxes of Solar Radiation and Absorption of Light by Plants. In *Plant Energetics* (pp. 31–54). essay, Academic Press.

Miletic, B. (2023, May 31). *Plants can remove petrol toxins from indoor air: UTS study*. Architecture & Design. https://www.architectureanddesign.com.au/news/plants-can-remove-petrol-toxins-from-indoor-air

Nicolini, E., Germanà, M. L., Marcon, G., Chiodi, M., Gutiérrez, Á., & Olivieri, F. (2022). Monitoring of the effect of solar radiation and rain on the building envelope with integrated vertical vegetation. *Building and Environment*, *226*, 109731. https://doi.org/10.1016/j.buildenv.2022.109731

Perrone, G. (2022, February 11). *Mexico City's pollution solution: Vía Verde Vertical Gardens*. Twenty Now. https://www.twentynow.com/sustainability-initiatives/innovation/mexico-citys-pollution-solution-via-verde-vertical-gardens/#google_vignette

Rameshkumar, S. (1970). Studies on Vertical Garden System: A new landscape concept for urban living space. *Journal of Floriculture and Landscaping*, 01–04. https://doi.org/10.25081/jfcls.2018.v4.3768

Singapore's initial National Communication: Under the United Nations Framework Convention on Climate Change, August 2000. (2000). . Ministry of the Environment.

Stollberg, M., & von Birgelen, A. (2023). Living wall plants are affected by and affect temperature: How to (not) measure plants' temperature in a living wall experiment. *Sustainability*, *15*(15), 11672. https://doi.org/10.3390/su151511672

Tai, B. (2015, September 15). *Sydney study proves how indoor office plants improve performance and productivity*. Architecture & Design. https://www.architectureanddesign.com.au/news/sydney-study-proves-how-indoor-office-plants-impro

Ulker, O. C., Ulker, O., & Hiziroglu, S. (2021). Volatile Organic Compounds (VOCs) emitted from Coated Furniture Units. *Coatings*, *11*(7), 806. https://doi.org/10.3390/coatings11070806

What are Vertical Gardens?. Ambius. (n.d.). https://www.ambius.com/green-walls/what-are-vertical-gardens/

Yuen, J. (2020, May 18). *Green Building Developments and Opportunities: Singapore*. HKTDC research. https://research.hktdc.com/en/article/NDI2MDUyMjk4