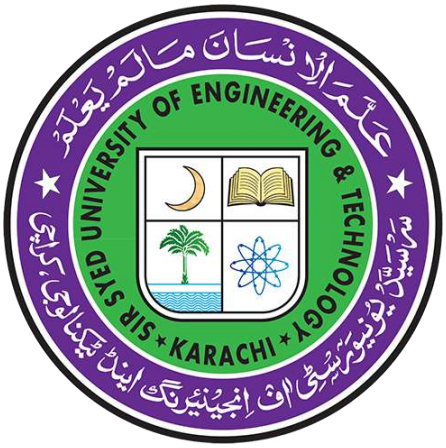
Design, Implementation and Analysis of Vertical Forest at Academia

BS CIVIL ENGINEERING, BATCH 2020s



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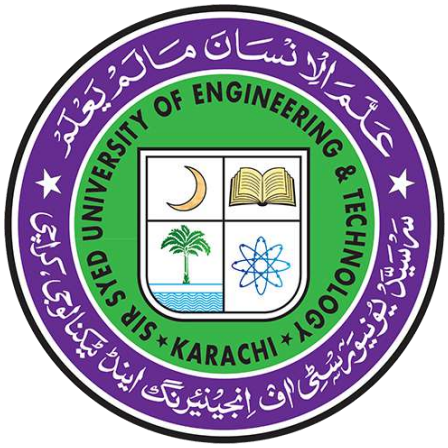

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CERTIFICATE

This is to certify that following students of Civil Engineering Department batch 2020s have completed their final year project in partial fulfillment for the award of bachelor's degree in civil engineering.

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ABSTRACT

Vertical forests represent a engaging combination of nature and urban architecture, offering innovative solutions to the challenges of rapid urbanization and environmental degradation. The primary objective is to seamlessly integrate architectural elements with the natural environment, resulting in an aesthetically enhanced landscape. Furthermore, the project aims to fulfill ecological responsibilities and improve the overall well-being of the academic community. It aims to establish a sustainable urban sanctuary in response to contemporary challenges such as climate change, air quality degradation, and urban development. The comprehensive study covers every aspect of the project's lifecycle, beginning with initial design concepts and culminating in a detailed examination of the Vertical Forest's impact on the academic ecosystem. Aside from conventional considerations regarding sustainability and environmental impact, this research examines how this unique green infrastructure affects the mental well-being of students and faculty members. The expected outcomes of this endeavor extend beyond conventional ecological benefits; it has the potential to nurture a deep reconnection between urban inhabitants and the natural world. Amid rapid urbanization, this initiative serves as a testament to sustainable urban development, aligning with key Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). Ultimately, this project aims to offer valuable insights into the complex interplay of design, the environment, and human dynamics, all while fostering a greener, more harmonious academic environment. It serves as an inspiring example for academic institutions and urban planners striving to create sustainable, harmonious urban living spaces. Through this comprehensive exploration, we aspire to enhance the beauty, sustainability, and quality of life within our academic community, advocating for a more harmonious coexistence between human-made structures and the natural world. Our collective endeavors are crucial for a brighter future.

PREFACE

The integration of nature and architecture is an effective approach to address environmental issues and enhance urban life. We present our final year project, **"Design, Implementation, and Analysis of Vertical Forest at Academia,"** which explores innovative approaches to sustainable design and urban greening. Our vision is to create a Vertical Forest that combines nature's aesthetic with human functionality. This report outlines the conceptualization, design, implementation, and analysis of the project. It is a testament to our commitment to addressing environmental challenges through sustainable design solutions. We hope this project inspires future generations of urban planners and architects.

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CHAPTER 1

INTRODUCTION

An innovative solution to rapid urbanization and environmental challenges, Vertical Forests harmonize nature and architecture. The purpose of this project is to explore a tailored Vertical Forest project at our academic institution, which enhances aesthetics, fulfills environmental responsibilities, and improves well-being. This project aims to address the negative impacts of climate change, reduce air pollution, and create an urban oasis that provides an ecological benefit. Amid urbanization's relentless pace, these arboreal structures excel in improving air quality, energy efficiency, biodiversity, and urban life. The study delves into design, execution, and analysis, transcending traditional boundaries to include mental well-being. The project reflects our commitment to sustainability and well-being, contributing to a greener and more harmonious academic ecosystem.

1.1 Background

In recent years, urbanization has generated unprecedented levels of human connectivity, innovation, and economic growth. Rapid urbanization has come at a price, a profound disconnects from nature, and a litany of environmental challenges. There has never been a greater need for innovative solutions to counteract environmental degradation and reintegrate nature into our cities than right now.

Vertical Forest presents a captivating and visionary solution to these challenges. By combining lush greenery with towering structures, Vertical Forest reimagines the essence of urban living. It enhances urban landscape's aesthetic appeal while addressing critical urban challenges. The project will improve air quality, increase energy efficiency, preserve biodiversity, and improve urban quality of life.

The significance of Vertical Forests goes beyond aesthetics and environmental stewardship’s structures hold the potential to foster a profound reconnection between urban inhabitants and the natural world, providing spaces for contemplation, relaxation, and rejuvenation. Amid the relentless pace of urban life, the nurturing embrace of nature within our cities can act as a sanctuary for the body and the mind.

1.2 Problem Statement

Amidst rapid urbanization, modern cities face a complex array of problems that threaten the ecological balance and the well-being of urban residents. The continuous growth of urban areas has led to increased environmental degradation, reduced green spaces, and a growing disconnect between city dwellers and nature. As urban centers continue to expand, the need for innovative solutions to these urgent issues becomes increasingly apparent.

Furthermore, within our academic institution, these challenges are clearly observable. Like other urban areas, our campus must grapple with the dilemma of accommodating growth

while enhancing the quality of life for its academic community. Balancing environmental responsibility, aesthetic appeal, and the health of students and educators amidst the constraints of urban development presents a multifaceted challenge.

The assimilation of Vertical Forest into our academic milieu emerges as a promising antidote to these quandaries. Nonetheless, the efficacious formulation, execution, and scrutiny of such an initiative necessitate the meticulous handling of an array of intricate facets encompassing engineering, environmental considerations, and human dynamics.

Consequently, the challenge at the heart of this study is dual:

i. To contrive, actualize, and scrutinize a Vertical Forest installation within our academic institution that enhances the campus's visual charm, simultaneously combatting environmental decline, and fostering the welfare of students and faculty members.
ii. To scrutinize the intricate tangle of engineering, environmental, and sociocultural nuances attendant to the integration of Vertical Forests into urban landscapes, with a particular emphasis on our academic domain.

1.3 Objectives

- **Design:** Create an aesthetically pleasing and ecologically sustainable design for
- the vertical forest.
- **Implementation:** Execute the designed plan for planting. Ensure proper care and maintenance to support plant growth and health.
- **Monitoring:** Continuously assess the growth, health, and environmental impact of the vertical forest. Regularly collect data on air quality and noise levels.
- **Analysis:** Evaluate the effectiveness of the vertical forest in improving air quality, reducing urban heat, and enhancing overall well-being. Analyze collected data to assess the project's success and environmental contributions.
- **SDG'S:** Achieving SDG 11 (sustainable cities and communities,) and SDG 13 (climate action).

1.4 Scope:

The focus of this study is on a vertical forest that has been designed, implemented, monitored, and analyzed within a university's premises.

1.5 Methodology

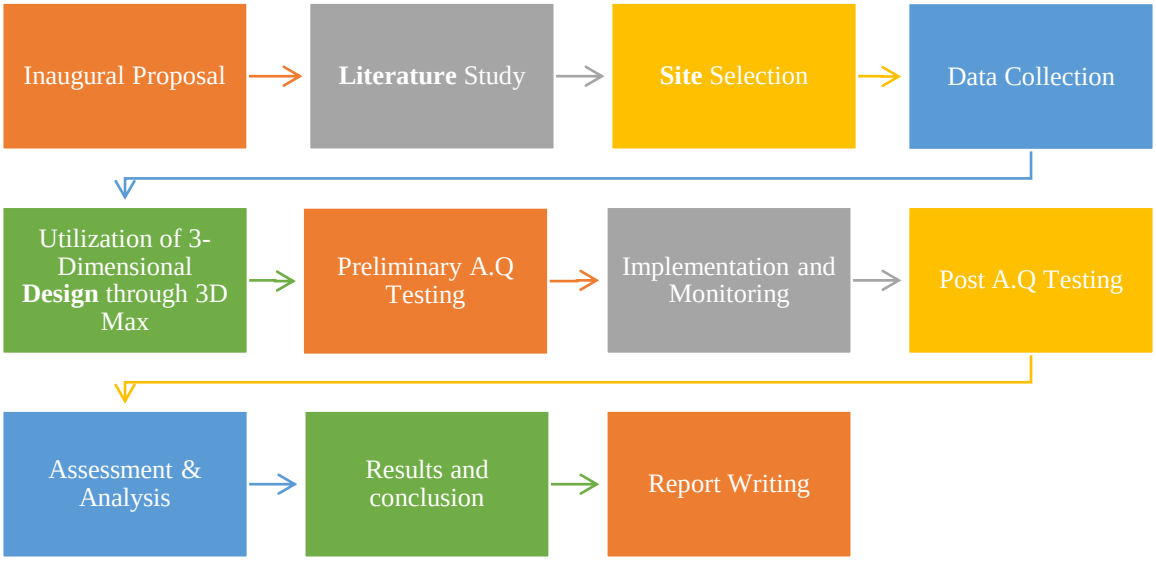

Figure 1.1 Methodology

1.6 Expected outcomes:

- Improved Air Quality
- Biodiversity Promotion
- Energy Efficiency
- Mitigation of Urban Heat
- Aesthetic Enhancement
- Noise Reduction
- Well-being Promotion
- Inspiration for Sustainable Design

CHAPTER 2

LITERATURE REVIEW

2.1 Environmental Benefits of Vertical Forest:

Vertical forest, exemplified by Milan's Bosco Vertical, play a vital role in enhancing urban environments. They absorb carbon dioxide and release oxygen, effectively combating pollution. Furthermore, these verdant structures provide refuge for avian and insect species, fostering biodiversity within cities. Their influence extends to mitigating the urban heat island effect by offering shade and evaporative cooling, thereby lowering temperatures in densely populated urban centers. An integral aspect is their seamless integration with surrounding green spaces, dissolving the boundaries between private and public domains [1].

2.1.1 Addressing Urban Environmental Challenges:

Vertical forest emerges as a solution to urban environmental challenges, providing green open spaces despite land constraints. Their implementation aids in preserving environmental quality while addressing climatological issues like the urban heat island effect and air pollution. Collaborating with other vertical greening systems such as green facades and walls, vertical forests contribute significantly to mitigating urban heat and global warming through integrated vegetation. Vertical plant walls, an integral part of these structures, optimize strategies for urban heat island mitigation and contribute to overall environmental quality, enhancing human comfort and well-being [2].

2.1.2 Enhancing Urban Greenery:

In densely populated metropolitan areas with limited land availability, innovative techniques like Aquaponics on building balconies increase greenery and improve air quality. Vertical forests serve as natural air filters, effectively removing harmful gases like CO2 and NO2, reducing their impact on both human health and the environment. Additionally, these green marvels mitigate the urban heat island effect by providing shade and cooling for their surroundings. They also boost biodiversity by creating habitats for birds, insects, and other wildlife, restoring ecological equilibrium within urban landscapes [3].

2.1.3 Air Quality and Beyond:

Vertical forest contributes to improved air quality by reducing particle concentrations, as observed in studies comparing downtown areas and urban forest parks. These structures are efficient at lowering concentrations of harmful particles like PM2.5 and PM10, contributing significantly to cleaner air. Moreover, vertical forests also enhance indoor air quality in high-rise buildings. Understanding particle dynamics in urban settings guides

assessments of indoor air quality, allowing the optimal placement of fresh air inlets in office buildings, avoiding areas with peak particle concentrations [4].

2.1.4 Acoustic Performance:

Beyond their environmental contributions, vertical greenery systems play a role in absorbing sound at low to middle frequencies, enhancing overall acoustic performance in urban environments [5].

2.2 Contribution of Vertical Forests to Sustainable Development Goals (SDGs):

Vertical forest, like the Bosco Vertical in Milan, play a pivotal role in advancing several Sustainable Development Goals (SDGs), showcasing their multifaceted impact on sustainable development [1].

2.2.1 SDG 11: Sustainable Cities and Communities:

Vertical forest significantly contribute to creating sustainable and livable urban environments by enhancing air quality, reducing pollution, and mitigating the urban heat island effect. These interventions align with the goal of fostering sustainable cities [2].

2.2.2 SDG 13: Climate Action:

Vertical forest actively combat climate change by absorbing carbon dioxide and releasing oxygen, thus facilitating carbon sequestration, and reducing greenhouse gas emissions.

2.2.3 SDG 15: Life on Land:

Vertical forest serves as vital habitats for birds, insects, and other wildlife, promoting ecological balance within urban landscapes. Their presence enhances biodiversity and supports the preservation of life on land.

2.2.4 SDG 3: Good Health and Well-being:

Vertical forest contributes to improving air quality in urban areas, mitigating the adverse effects of air pollution on human health and well-being.

2.2.5 SDG 9: Industry, Innovation, and Infrastructure:

The innovative design and implementation of vertical forests exemplify advancements in sustainable architecture and urban infrastructure [3].

2.3 Enhancing Student Well-being Through Physical Environments:

2.3.1 Improved School Environments:

Research indicates that optimizing the physical environment in schools, which includes factors like indoor air quality, lighting, and acoustic conditions, can significantly enhance

student health outcomes [6]. A well-maintained school environment fosters better learning conditions.

2.3.2 Forest Benefits for Students:

Forests offer a range of benefits to students, including improved mental health, reduced stress levels, and increased cognitive function. Spending time in natural settings like forests can also enhance students' creativity and attention restoration, positively impacting their overall well-being [6].

2.3.3 Green Spaces in Schools:

The inclusion of green spaces within school premises can create a more conducive learning environment. This presence of nature has the potential to improve students' overall academic performance, highlighting the importance of incorporating greenery into educational settings [7].

2.4 The Rise of Vertical Forests in Global Cities:

2.4.1 Global Adoption:

Cities worldwide, such as Utrecht and Eindhoven in the Netherlands, have enthusiastically embraced the innovative concept of vertical forests, reimagining urban living with greenery at its core [1]. This transformative trend is reshaping urban landscapes.

2.4.2 Historical Roots:

The origins of vertical greening systems can be traced back to around 2000 years ago in the Mediterranean region, where vine trees were ingeniously used to provide shade on building facades. This historical practice marked the inception of vertical greenery [2].

2.4.3 Bosco Vertical in Milan:

A remarkable manifestation of this concept is the Bosco Vertical project in Milan, Italy, masterminded by architect Stefano Boeri. This pioneering project beautifully combines residential buildings with lush green balconies, setting a global precedent for integrating nature into urban living spaces [1].

2.4.4 Chinese Enthusiasm:

Chinese cities, exemplified by Nanjing, have enthusiastically adopted vertical forest projects. The urban forest park in Nanjing, studied in various sources, showcases China's strong interest in this innovative concept, highlighting its global appeal.

2.4.5 Global Adoption Continues:

Beyond Europe and Asia, cities like Singapore, Paris, and Vancouver have also wholeheartedly embraced vertical forests. This movement aims to enhance urban green spaces, elevate air quality, and promote biodiversity, emphasizing the global recognition of the benefits of vertical forests [4].

2.5 Case Studies

2.5.1 Case Study No.01

The geography of vertical forests: Exploring the green city

The Bosco Vertical, or Vertical Forest, in Milan has garnered international acclaim for its innovative approach to urban architecture and its positive impact on the daily lives of residents. This case study delves into the development of this groundbreaking project and explores how it has transformed the urban landscape.

The study focuses on the spatial dynamics of the Bosco Vertical and how it interacts with its surrounding public areas. By considering the perspectives of residents and individuals who encounter the building in their daily routines, the research aims to understand the everyday encounters and experiences within this unique architectural marvel.

A critical analysis is conducted to deconstruct the various interpretations attributed to the Bosco Vertical. This analysis highlights the crucial role that the vertical forest plays in enhancing the daily urban experiences of its inhabitants. The study argues that vertical forests, like the Bosco Vertical, have the potential to improve the well-being of local resident, but only if they are facilitated and encouraged to engage with these verdant structures from the perspective of nearby public spaces.

Furthermore, the research draws attention to the global phenomenon of vertical forests. Cities worldwide, including Utrecht and Eindhoven in the Netherlands, have embraced this concept as a tangible expression of the green urban agenda. This trend underscores the growing recognition of the symbiotic relationship between nature and urbanity in contemporary urban planning practices.

Overall, this case study provides a comprehensive examination of the Bosco Vertical and its impact on urban daily life. By considering the perspectives of residents and analyzing the spatial dynamics of the building, the study sheds light on the transformative power of vertical forests and their potential to enhance the well-being of urban inhabitants.[1]

2.5.2 Case Study No.02

Vertical forest: green open space alternative in urban area development

To effectively implement vertical forests as a solution to the scarcity of Green Open Space (GOS), it is crucial to make regulatory adjustments and establish incentive frameworks. These adjustments and frameworks will serve as motivators for local authorities and the private sector to actively participate in achieving green open space objectives.

The historical roots of vertical forests can be traced back to ancient times, with the Hanging Garden of Babylon serving as a prime example. This historical context highlights the long-standing recognition of the benefits and beauty of vertical forests.

To examine the application of vertical forests in Indonesia and their contribution to environmentally driven sustainable development goals, this study employs a qualitative methodology grounded in sustainable development theory. By using this approach, the study aims to provide a comprehensive understanding of how vertical forests can be effectively utilized in Indonesia.

Currently, regulations in Indonesia mandate a minimum allocation of 30% of the total area for green open space development, as specified by Law No. 26 of 2007. However, an alternative approach takes into consideration factors such as population and oxygen demand to calculate the necessary green open space. This alternative approach offers a more nuanced perspective on urban greenery planning, ensuring that the allocation of green open space is based on the specific needs and demands of the population.

Overall, the present study seeks to explore the potential of vertical forests as an innovative solution to address the scarcity of Green Open Space in urban areas with limited land availability. By aligning with the national sustainable development agenda and enhancing the competitiveness of the green city initiative, vertical forests can play a crucial role in promoting a harmonious balance between urban development and environmental quality.[2]

2.5.3 Case Study No.03

Vertical Forest to Clean Environment

The study explores the concept of vertical forests as a potential solution to mitigate air pollution in urban areas. Vertical forests entail the cultivation of plants and trees on the balconies and facades of buildings, which can effectively absorb carbon dioxide and other pollutants from the atmosphere, thereby generating fresh oxygen. The Bosco Vertical project in Milan is cited as an example of a vertical forest initiative, featuring over 20,000 plants and 700 trees growing on the balconies of two residential towers.

It Proposes the utilization of aquaponics techniques to cultivate plants for vertical forests, instead of soil-based planting. Aquaponics is a water-based system in which fish waste provides nutrients for the plants. This method requires less water and imposes less structural load on buildings compared to traditional soil-based planting. The text elucidates the components and mechanisms of an aquaponics system and presents test results indicating favorable pH and dissolved oxygen levels for growing fish.

In conclusion, the text advocates vertical forests as a promising approach to mitigate air pollution in urban areas. The implementation of aquaponics techniques for vertical forest cultivation could offer environmental benefits while being more resource-efficient than traditional soil-based planting. Vertical forests have the potential to enhance urban air quality and foster a healthier living environment for urban dwellers.[3]

2.5.4 Case Study No.04

Comparison of particle concentration vertical profiles between downtown and urban forest park in Nanjing (China)

The present study aimed to conduct a comparative analysis of the vertical distributions of PM2.5 and PM10 concentrations in downtown Nanjing and a surrounding national forest park. The results indicated that in the forest park, particle concentrations exhibited a negative association with height, whereas in downtown, peak values were observed at the height of roadside tall trees instead of at ground level. Unmanned aerial vehicle (UAV) measurements revealed that trees along the road reduced PM2.5 and PM10 concentrations by 24% and 26%, respectively, above the road. Correlation analysis demonstrated that particle concentrations exhibited higher correlations with meteorological parameters in downtown compared to the forest park. Temperature and relative humidity were found to contribute to the variation of particle concentrations at different heights. The findings of this study provide valuable insights into the dynamic characteristics of particles in urban areas and have significant implications for assessing indoor air quality in high-rise buildings, thereby contributing to the creation of a healthier environment for city residents.[4]

2.5.5 Case Study No.05

Vertical Forest Engineering Applications of Vertical Forests with Self-Growing Connections in High-Rise Buildings

This paper examines the integration of vegetation with buildings, specifically focusing on vertical greenery systems such as vertical forests, within metropolitan areas. It emphasizes the advantages of green infrastructures at both urban and building levels, encompassing enhancements in microclimatic conditions and psychological well-being.

The study delves into the design considerations that architects, structural engineers, and botanists must consider when implementing living architectures. These considerations encompass climatic factors, structural support systems, and maintenance requirements.

To ensure the stability of vertical forests, the concept of self-growing connections is proposed as an alternative to conventional steel cages and bracings. This innovative approach aims to provide a more sustainable and efficient solution.

The primary objectives of this paper are to raise awareness regarding the potential of integrating vertical greenery with buildings, offer practical application considerations, and inspire future advancements in typologies and integration with natural forests.[5]

2.5.6 Case Study No.06

The role of physical environment on student health and education in green schools

This paper investigates the influence of physical school environments on student health and education, with a particular emphasis on green schools. Green schools are designed to establish sustainable and healthier spaces for students by enhancing factors such as indoor air quality, lighting, and acoustic conditions. Research has shown that improved physical environments in schools can have a positive impact on student health outcomes. This paper synthesizes findings from green design studies and school outcomes studies to assess the potential effects of green school design features on student health outcomes. It covers a range of topics, including an overview of the green concept, existing guidelines for green schools, attitudes toward green schools, and the condition of physical environments in non-green schools. The potential effects of the physical environment on school children are discussed, including national statistics and findings from school research studies. The paper concludes by highlighting gaps in knowledge in the field of green school research and providing overall conclusions.[6]

2.5.7 Case Study No.07

Impact of views to school landscapes on recovery from stress and mental fatigue

This paper aims to examine the effects of green landscape views on student performance and stress recovery in an academic setting. To achieve this, a randomized controlled experiment was conducted with a sample of 94 high school students from five different high schools. The participants were assigned to classrooms that either had windows overlooking a built space or a green space.

The results of the study indicate that students who had classroom views of green landscapes experienced significant improvements in their attentional functioning and were better able to recover from stressful experiences. These findings suggest that incorporating green landscapes into school environments can have a positive impact on student performance and overall well-being.

The implications of these findings emphasize the importance of considering green spaces in the selection, design, and renovation of school sites. By incorporating green spaces into school environments, educators and policymakers can create a more conducive learning environment that promotes student well-being and academic success.

This research contributes to the existing literature by providing further insights into the potential benefits of green environments in promoting student well-being and academic achievement. By understanding the positive effects of green landscapes on students, educators and policymakers can make informed decisions regarding the design and

implementation of school environments that prioritize student well-being and academic success.[7]

2.5.8 Case Study No.08

Retrofitting of an existing residential building in Cairo using green facade technology: understanding the real benefits of a vertical forest concept in Egypt

This thesis investigates the potential benefits of applying vertical forest concepts to buildings in Cairo, Egypt. Cairo faces several environmental challenges, including air and noise pollution, greenhouse gas emissions, and the urban heat island effect. The project "Cairo Vertical Forest" aims to address these issues through vertical forestation and retrofitting existing buildings with green facades and envelopes.

The literature review found that green building envelopes can improve air quality, reduce noise levels and urban heat islands. They also improve quality of life by creating a natural environment that promotes biodiversity. As a case study, an existing residential building in the Maadi neighborhood of Cairo was selected for retrofitting with a green facade. Since residential buildings account for 51.3% of Egypt's annual energy consumption, the case study focused on analyzing apartment cooling loads, solar gains and conductive heat gains.

The case study was conducted using Autodesk Revit 2022 to establish a workflow for assessing green building envelopes. Reductions were achieved in cooling loads and heat gains, but no significant reductions were found in the overall building energy consumption. In conclusion, while green facades show potential for addressing some environmental challenges, their impact on overall energy use appears to be limited. More research is needed to optimize the design of green facades for maximizing benefits in the Egyptian context.[8]

2.5.9 Case Study No.09

Indirect Economic Effects of Vertical Indoor Green in the Context of Reduced Sick Leave in Offices

The article discusses the economic benefits of vertical indoor greenery in office spaces due to its positive effects on relative humidity and air quality, which can lead to reduced sick leave. Low humidity in winter months can cause health issues like respiratory diseases and increase sick leave, especially due to colds and flu. Vertical greenery has been shown to improve indoor air humidity, especially in winter.

Vertical indoor greenery systems do have installation and maintenance costs, but the author argues these costs can be offset by savings from reduced sick leave due to employees taking fewer sick days when the air quality improves. The author analyzed data from six greened rooms and three non-greened rooms in Vienna, finding that the greened rooms had

significantly higher levels of hygrothermal comfort, a measure of air temperature and humidity comfort.

Based on the costs of one sick day for an employee and average annual income data, the author calculates that the greening systems in the analyzed rooms would pay for themselves after 1.4 to 6.3 years due to savings from reduced sick leave. The large range depends on factors like the size of the greening system and how many sick days are avoided. The author also provides a generalized approach to calculate the payback period for vertical greenery based on various inputs like installation costs, size of the office space, and number of avoided sick days.

In conclusion, the analysis shows that the economic benefits of vertical greenery due to reduced sick leave can offset the costs of installing and maintaining the systems, though there are uncertainties in the assumptions and calculations. The author recommends considering other potential benefits of greenery beyond just improved air humidity to strengthen the case for vertical indoor greenery.[9]

2.5.10 Case Study No.10

Climate Effects on Vertical Forest Phenology of Fagus sylvatica L., Sensed by Sentinel-2, Time Lapse Camera, and Visual Ground Observations

This article discusses Vertical Forest, a sustainable residential building model that aims to reforest cities vertically. Vertical Forest towers contain many plants and trees on their facades which help make the building more sustainable in several ways.

The first Vertical Forest building was constructed in Milan, containing 900 trees and over 20,000 plants across its two towers. The vegetation system creates a microclimate, produces humidity, absorbs CO2 and dust particles, and produces oxygen.

The Vertical Forest increases biodiversity by providing habitats for birds and insects. The trees and plants filter dust particles and create humidity while absorbing CO2 and producing oxygen. Vertical Forests also act as anti-sprawl measures by providing high-density housing in a small footprint.

The choice and placement of the trees and plants on the facades was carefully designed based on their height and positioning. The vegetation changes with the seasons, creating variable landscapes.

Building regulations govern the management and maintenance of the plants. The irrigation needs were also considered during the planning process based on the plant distribution across floors and positions.

In summary, Vertical Forest aims to reforest cities vertically through sustainable high-rise residential buildings covered in vegetation, bringing environmental and ecological benefits.[10]

2.5.11 Case study No.11

Evaluation of green walls as a passive acoustic insulation system for buildings

Vertical greenery systems like green walls have the potential to provide benefits like noise attenuation, energy savings, and stormwater control for buildings. However, there are limited studies evaluating the sound insulation capabilities of green walls. The available data is scattered and based on different types of green wall designs.

This study evaluated a modular-based green wall system to gather knowledge about their contribution to noise reduction for buildings. Laboratory tests were conducted according to international standards to accurately measure the acoustic properties of the green wall.

The results showed a weighted sound reduction index (Rw) of 15 dB, indicating the green wall provided some noise insulation but less than other traditional building materials due to its lower mass. However, improvements to the green wall design like sealing the joints between modules could potentially increase the sound insulation to Rw = 18 dB.

A sound absorption test in a reverberation room showed a weighted sound absorption coefficient of 0.40 for the green wall. The green wall showed similar or better sound absorption characteristics than some common building materials, especially at lower frequencies.

In conclusion, while green walls show promise as a passive noise control solution for buildings, more studies are needed based on different green wall designs to determine their true noise attenuation capabilities. Some simple design improvements could potentially enhance the sound insulation provided by modular green walls.[11]

CHAPTER 3

3.1 References

[1] Visser, M. (2019). *The geography of vertical forests: Exploring the green city*. Studenttheses.uu.nl. https://studenttheses.uu.nl/handle/20.500.12932/35208

[2] Pribadi, M. A., Septina, A. D., Lugina, M., & Indartik, I. (2021). Vertical forest: green open space alternative in urban area development. *IOP Conference Series: Earth and Environmental Science*, *909*(1), 012012. https://doi.org/10.1088/1755-1315/909/1/012012

[3] Goud, R., Chauhan, N., Lokhande, H., & Bohre, S. (2018). Engineering and Technology (A High Impact Factor. *International Journal of Innovative Research in Science, 7*. https://doi.org/10.15680/IJIRSET.2018.0703057

[4] Liu, F., Zheng, X., & Qian, H. (2018). Comparison of particle concentration vertical profiles between downtown and urban forest park in Nanjing (China). *Atmospheric Pollution Research*, *9*(5), 829–839. https://doi.org/10.1016/j.apr.2018.02.001

[5] Apa) Wang, X., Gard, W., & Van De Kuilen, J-W. (2019). *Vertical Forest Engineering: Applications of Vertical Forests with Self-Growing Connections in High-Rise Buildings* (pp. 184–197). https://pure.tudelft.nl/ws/portalfiles/portal/68749570/Vertical_Forest_Engineering._Applications_of_Vertical_Forests_with_Self_Growing_Connections_in_High_Rise_Buildings.pdf

[6] Selen Okcu, Ryherd, E. E., & Bayer, C. W. (2011). The role of physical environment on student health and education in green schools. *Reviews on Environmental Health*, *26*(3). https://doi.org/10.1515/reveh.2011.024

[7] Li, D., & Sullivan, W. C. (2016). Impact of views to school landscapes on recovery from stress and mental fatigue. *Landscape and Urban Planning*, *148*, 149–158. https://doi.org/10.1016/j.landurbplan.2015.12.015

[8] ASHRAF, M. (2023). Retrofitting of an existing residential building in Cairo using green facade technology : understanding the real benefits of a vertical forest concept in Egypt. *Polimi.it*. http://hdl.handle.net/10589/185913

[9] Hollands, J., & Azra Korjenić. (2021). Indirect Economic Effects of Vertical Indoor Green in the Context of Reduced Sick Leave in Offices. *Sustainability*, *13*(4), 2256–2256. https://doi.org/10.3390/su13042256

[10] Uphus, L., Lüpke, M., Yuan, Y., Benjamin, C., Englmeier, J., Fricke, U., Ganuza, C., Schwindl, M., Uhler, J., & Menzel, A. (2021). Climate Effects on Vertical Forest Phenology of Fagus sylvatica L., Sensed by Sentinel-2, Time Lapse Camera, and Visual Ground Observations. *Remote Sensing*, *13*(19), 3982–3982. https://doi.org/10.3390/rs13193982

[11] Azkorra, Z., Pérez, G., Coma, J., Cabeza, L. F., Bures, S., Álvaro, J. E., Erkoreka, A., & Urrestarazu, M. (2015). Evaluation of green walls as a passive acoustic insulation system for buildings. *Applied Acoustics*, *89*, 46–56. https://doi.org/10.1016/j.apacoust.2014.09.010