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Designing for Sustainability: Environmental Impact of Vertical Green Systems on the West Facade using Innovative Techniques: A Building Case in Dhaka

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ABSTRACT

Dhaka, the capital of Bangladesh, is a densely populated city where urban development largely ignores the concept of greenery, resulting in adverse environmental impacts. As a result, the city is experiencing higher temperatures, poor air quality, biodiversity loss, and limited horizontal green spaces. This study examines the potential of integrating Wood Plastic Composite (WPC) louvers with Vertical Green Systems as a sustainable solution for tropical climates. This paper explores a six-story local office building, designed with the involvement of one of the authors, which has a west-facing orientation and regularly receives solar radiation. Integrating these techniques successfully reduces the environmental impact and promotes habitats for urban fauna and users' well-being. Based on frequent observations, the paper highlights the benefits and offers recommendations for future design practices.

Keywords: Vertical Green Systems, Wood Plastic Composite, Sustainability, Sustainable Building Materials, Dhaka, Environmental Impact, Biodiversity, Green Facades, Air Quality Improvement, Energy Efficiency, Innovative Techniques, Environmental Policy, Eco-friendly Solutions.

INTRODUCTION

The physical structure of Dhaka has changed over time due to economic forces to accommodate the demands of the city's rapidly growing urbanization. However, the current trend of these changes has drawn criticism for ignoring sustainability, which has resulted in increasing environmental issues in densely populated areas of the city. This paper examines a six-story office building designed with a west-facing vertical green facade, in which one of the authors was involved. The project addresses sustainability by focusing on air quality, rising temperature, building cooling, biodiversity, and users' well-being.

The vertical green systems were inspired by the greenery techniques found in the ancient Hanging Gardens of Babylon circa 600 BCE [1-3]. These approaches are becoming a cutting-edge way to solve environmental problems in crowded cities, improving ecosystems and people's quality of life [2, 4, 5]. Through the lens of the selected building, the paper explores how integrating nature into urban settings can enhance user's well-being, reduce the urban heat island effect, and contribute to a healthier environment in densely populated areas. Ultimately, the paper aims to add knowledge in this field, providing insights that can inspire the development of similar projects in the future.

OBJECTIVES

The paper intends to explore the key elements of vertical green systems, emphasizing creative methods for incorporating Wood Plastic Composite (WPC) louvers strategies and plant selection into the building's facade. The study investigates the challenges and opportunities of integrating vertical green facades into urban architecture and provides practical solutions for overcoming these challenges.
The objectives are as follows:

- **Design Exploration**: To examine the creative methods of integrating WPC louvers and plant systems on the building's west-facing façade, focusing on environmental impact and aesthetic value.
- **Sustainability Focus**: To understand the relationship between biology, environmental science, and sustainable design in creating energy-efficient vertical green facades suitable for tropical climates.
- **Practical Guidelines**: To offer actionable insights and recommendations for stakeholders, including architects, designers, and policymakers, on integrating vertical green systems into the building design process to achieve environmental, social, and economic benefits.

LITERATURE

Vertical Green Systems: A Key to Sustainable Design: The concept of sustainability emerged in the late 20th century. It focused on meeting current needs without compromising the ability of future generations to meet their own while protecting natural resources and ecosystems for long-term benefits [6]. During the transition towards sustainable development, the greening of architecture has received widespread attention to achieve environmentally friendly and livable spaces [5, 7]. Features such as energy conservation, thermal insulation, environmental quality, and health benefits became an integrated part of the concept of vertical green systems [1].
These systems have a wide range of benefits, such as reducing urban heat island effects, improving air quality, reducing noise pollution, lowering energy consumption, and supporting biodiversity [2, 5]. The more the city focused on sustainability, the more vertical green systems became an important feature of its architecture. Thus, these systems foster harmony between urban development and the natural environment [2].
Greenery Systems_Vertical Green Façade: A façade is a symbol of culture and architecture, usually representing the face or character of a building [8, 9]. A green vertical facade is an innovative approach to using plants as part of vertical surfaces such as walls, claddings, and rooftops to create green spaces for urban settings. However, this concept is not new; it has gained importance in environmental, social, and aesthetic benefits over the last two decades [5, 10]. Based on various factors, such as plants, supporting elements, and irrigation systems, green facades can be classified into direct and indirect green facades. In a direct green façade, plants like ivy grow directly on the wall, whereas in an indirect green façade, plants require support structures such as modular guides. These systems have a significant impact on a building's aesthetic, as well as environmental and social benefits [4, 11, 12]. The case study building has an indirect green façade designed with a permanent planter box on each floor and WPC louvers as support structures.
Integrating WPC Louvers and Vertical Green Façades: It is an innovative, modern and sustainable technique, where aesthetics and energy efficiency in buildings are attained through the integration of

WPC (wood plastic composite) in vertical green facades. This approach supports technical challenges along with ensuring durability, structural integrity, and a better environment. The concept of louvers and greenery works in harmony to enhance heat transmission and thermal control in buildings [13].

Both WPC and vertical green systems act as shading devices while accommodating visual comfort but reducing direct glare from glass façades. Studies show that vertical green systems, by providing shade and cooling, help reduce the urban heat island and, in many cases, boost indoor temperature reduction up to 3.0 °C [3, 5, 14]. Moreover, a fully covered green façade can reflect or absorb intense solar radiation in summer through its leaves (depending on the plant type and density) ranging from 40% to 80% of the received radiation. Finally, this system offers better shading opportunities than other types of vertical greenery, as it can cover a larger building surface area.

METHODOLOGY

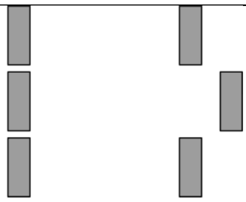
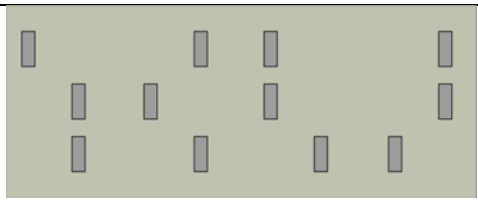
This paper investigates the design, implementation, and performance of a vertical green façade of a six-storied office building located in a busy area at Mirpur-13, Dhaka, Bangladesh. The methodology applied in the research is based on site visits, direct observations, and detailed evaluation of the design considerations and their outcomes in designing the vertical green system. Moreover, this research was focused on practical observations and step-by-step design processes, not relying on computer-based projection models since they are not always dependable. Key sections of methodology are discussed below:

Design Philosophy and Inspiration: The design integrated vertical green systems in the building's west-facing façade to address the challenges of Dhaka's tropical monsoon climate, where the solar radiation from the west is typically very intense. The initial idea was to integrate the architectural design with nature to address the environmental impact as well as create an aesthetically pleasant and comfortable atmosphere. The inspiration came from the Hanging Garden of Babylon and modern green architectural projects that aim to improve air quality, enhance biodiversity, and create a microclimate around the building. The design deeply considered the locally available materials and plant species that suit the tropical climate of Dhaka. Additionally, psychological benefits for the users have been achieved by this approach.

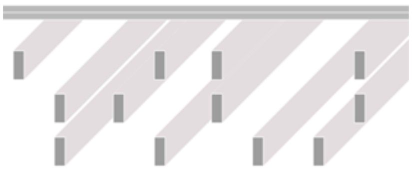
Implementing Strategy

Primary Louver Design Concept: During the initial design phase, wooden louvers were the prime selection. The depth of the louvers was determined to be 30 cm (figure 01) for better shading and to enhance the aesthetics of vertical greenery. However, after considering the initial cost and the long-term maintenance processes associated with wood in outdoor environments (especially in a tropical climate like Dhaka), the design team shifted to metal louvers. Metal louvers, such as mild steel metal, have a longer life than wood but have demerits such as rusting, which involve regular maintenance and repainting. The decision indicated a compromise between aesthetics, functionality, and long-term practicality.

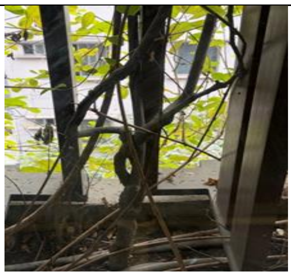
WPC Louvers: The important turning point came when WPC louvers were found in local markets. Although these louvers require a costly initial setup, they incur hardly any maintenance costs while offering long-term benefits. However, a possible limitation found by the design team during the literature study on their properties is that the louver could bend if exposed to harsh sunlight. Additionally, locally available WPC louvers were only 10 cm deep instead of 30 cm**,** which was required in the design. To resolve these issues, the design team innovatively combined three layers of separated 10 cm louvers and split them slightly (figure 02) to allow maximum shading while creating a more promising environment for plant growth towards the west orientation (figure 03).

Figure 01: Wooden Louver	**Figure 02: Idea of Splitting the MS louver**	**Figure 03: Arrangements of Louver Considering West Orientation**
		

Shading and Security: The final arrangement of WPC louvers helped to cast shadows on the façade, providing both aesthetic value and functional shading. It also helped to control heat and reduce glare. Additionally, it offered a safety feature by replacing the traditional grill system in front of windows or glasses while fostering natural airflow and visibility (figure 04).

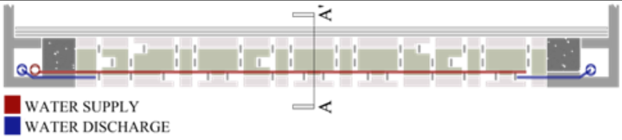
Figure 04: Idea of Arrangements of Louver Considering Shading and Security (a. During Design b. During Construction c. After Completion)		
		
(a)	(b)	(c)

Plant Selection and Biodiversity: The plants were carefully selected to suit the local climate, are low-maintenance, and are air-purifying, including Bougainvillea (white and pink flower), variegated Bougainvillea, and Dracaena trifasciata. Additionally, fragrant flowers like Arabian Jasmine, Hibiscus, Ixora coccinea, Combretum indicum, Duranta erecta and Clematis flammula were chosen to attract birds and butterflies. Over time, some of the flowering plants did not work as expected; the Bougainvillea, Ixora coccinea, Combretum indicum, and Duranta erecta were found to be very sustainable and efficient to support biodiversity (figure 05).

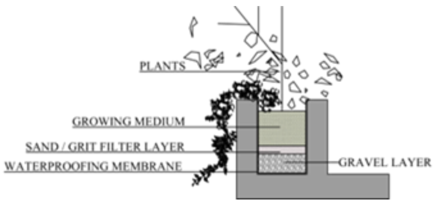
Figure 05: a. Mature Plants b. Bougainvillea c. Birds' Nests Support Biodiversity		
		
(a)	(b)	(c)

Watering and Maintenance Systems: To maintain the vertical green systems, a sustainable watering system was installed. The design simplifies the operation of the water line opening and incorporates an efficient discharge mechanism. Furthermore, regular maintenance involves pruning to control the growth of plants, using regular fertilizer to enhance soil fertility, and using insecticides or pest control treatments to protect plants from diseases. Over these years, the plants matured, and the vertical green system now serves as a shelter for birds and other species, further adding value to the building's ecology (figure 06).

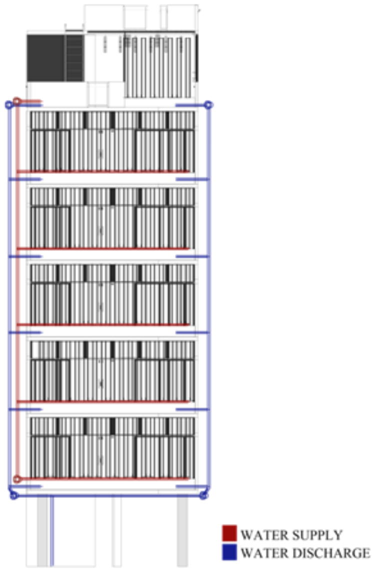
Figure 06: a. Water Supply and Discharge b. Section AA' (Planter Box Details) c. Diagram of watering and discharge Systems in Whole Plantation Area of the Building



(a)



(b)



(c)

Site Visits and Observational Data

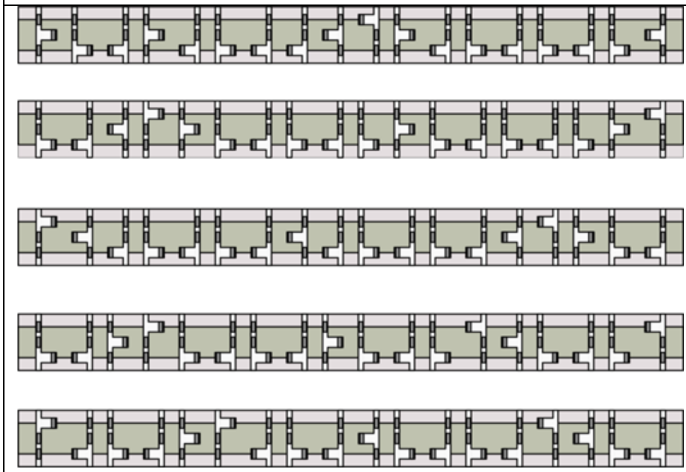
Physical Observation: The research data was collected by regular site visits, typically 4 (four) times a year throughout the last six years, conducted by Author 1. The focuses were on plant growth, the performance of WPC on the west façade, and the overall effect of the buildings on the microclimate and users well-being.

Long-Term Performance: Regular observations of the building's efficiency have helped justify the initial design ideas. Through continuous monitoring, the performance of the façade's shading, its impact on energy consumption, biodiversity opportunities, and added value in the building's aesthetic and social aspects have been explored (figure 07).

Figure 07: Case Study Building over Various Time

INNOVATIONS AND LESSONS LEARNED

Innovative Louver System: The most remarkable application of this project was the creative use of WPC louvers in the plantation area in front of the large windows. By splitting the louvers, the team achieved an ideal solution for both shading and plant support, effectively mitigating solar heat gain and enhancing the overall façade's aesthetic appearance. This innovation also eliminated the traditional security grill system and supported biodiversity (figure 08).

Figure 08: a. Louver Arrangements at Different Floors b. 3D View of Louver Arrangements	
	
(a)	(b)

Sustainability and Adaptability: The achievement of this project was the integration of nature-based solutions to urban buildings, particularly in tropical climates like Dhaka, which in parallel improved the both building's aesthetic and ecological value. In addition, the vertical green façade in the project has a great impact on mitigating temperature and energy consumption and allowing fresh air into the building.

Cost and Maintenance Considerations: The initial installation cost of the vertical green façade was expensive compared to the traditional facade. However, the low maintenance features of the WPC louvers and the self-sufficient plantation system have been justified as cost-effective in the long term. The project emphasized creative design options by using locally available plant species and materials to lower costs.

Despite the upfront expense, the system lowered energy consumption, supported biodiversity, and enhanced users' well-being. These features demonstrate the long-term economic and ecological value of integrating nature-based solutions into urban settings, particularly in tropical climates like Dhaka.

DISCUSSION

Impacts of Vertical Green Systems (Environmental, Social and Economic): Vertical greenery has a multifaceted impact, such as minimizing environmental challenges and maximizing social, economic, and ecological benefits. Its influence goes beyond many sectors, from resource utilization to community well-being. Some of the key impacts are given below:

Environmental Impact

Heat Reduction and Energy Efficiency: The most significant effect of vertical green systems is temperature reduction while improving the energy efficiency of a building [15]. By integrating WPC louvers and green plants, the foliage and shades effectively control heat and reduce annual energy demands in tropical countries. These systems manage heat gain and loss through shading, thermal insulation, and evaporation. They mitigate urban heat island effects, regulate humidity, and enhance the urban microclimate [7, 15]. Research from the National University of Singapore illustrates that energy consumption can be reduced by up to 5% if the building's temperature is decreased by 1 degree Celsius [12].

Air Quality Improvement: The Vertical Green systems also play a pivotal role in absorbing dust and pollutants like CO_2, NO_2, SO_2, O_3, and particulate matter (PM_{10}) while purifying the air and releasing oxygen [5, 7, 15, 16]. The green pigments in the leaves absorb sunlight during photosynthesis, which improves air quality by absorbing CO2 during the day [2, 12]. Dhaka, suffering from high levels of air pollution, could benefit from these systems.

Biodiversity Support: The façade designed with WPC and greenery arrangements supports local biodiversity, providing habitats for various plant species and insects, promoting coexistence between urban architecture and nature. However, certain knowledge of plant requirements and the specific needs of faunas is required to design vertical greenery for biodiversity support [15]. Careful selection of species, such as flowering plants for pollinators or climbing plants for bird habitats, enhances biodiversity and supports ecological resilience [17].

Social and Health Impact

Community Engagement: The façades of buildings can express the cultural, social, economic, and technological aspects of a society. These serve as the first point of interaction between buildings and people [8]. Vertical green facades can enhance social integration by fostering community engagement [2, 15, 18]. These features can also promote healthier and enlivened communities while exhibiting the social responsibility associated with sustainable architectural practice.

Health Benefits: The green façades improve human health by reducing stress, anxiety, and depression [4, 7, 10, 16]. It enhances psychological benefits and increases overall quality of life [1, 2, 4]. Regular exposure to and engagement with plants can result in direct health benefits and improve the living and working environment. For example, exposure to green spaces, in general, can reduce symptoms like headaches to a minimum of 20% [19]. Additionally, workplaces with green elements can reduce sick leave days by about 10%, along with an overall increase in work satisfaction and performance [7, 20].

Economic Impact

Cost-effectiveness: Viewing economically alone, Vertical green systems can be seen as an expensive technology. However, considering multifaceted benefits such as social, environmental, and health benefits, these systems are a cost-effective option. Its major cost includes the expenses of plants, growing medium, planter area treatment, and watering system. Its installation and maintenance costs are normally higher than traditional cladding systems. To ensure an affordable design, it is advisable to reduce initial setup and maintenance costs by choosing the most suitable plants in the region and using locally available materials. Ultimately, when a comparative life-cycle cost analysis is conducted, this system will be worthwhile [11].

Energy Savings and Property Value Boost: A key economic benefit of vertical green systems in tropical climates is their ability to reduce building temperatures, thereby minimizing energy costs [11]. Studies show that green space improves occupants' satisfaction and increases rental and sale prices, thereby raising property value. Additionally, greenery on building façade can have a positive economic impact on building owners and developers [5, 7].

Challenges and Opportunities

In recent years, the popularity of vertical green facades in architectural projects has risen significantly. These façades substantially protect buildings from humidity, temperature variation, rain, and ultraviolet radiation [11]. However, architects and designers often fail to fully explore and utilize the benefits of the technology [10]. In countries like Bangladesh, the main focus of implementing vertical greenery is aesthetic rather than environmental, social, and economic values. Additionally, many teams are not well equipped with technical knowledge, highlighting a research gap in maximizing the benefit of the systems.

Historically, building development often neglected social and psychological dimensions of public spaces and architectural designs, affecting the user's well-being [21]. Vertical green systems can improve the overall urban landscapes and contribute to innovative solutions that align with the Sustainable Development Goals (SDGs). Considering these factors while designing buildings, architects can fulfill environmental objectives while promoting community engagement and improving overall well-being. Ultimately, integrating aesthetics with these values can contribute to sustainable and vibrant urban life.

The orientation of the vertical green façade significantly impacts their effectiveness. For instance, plants on the east-facing façade tend to grow better than other orientations [22]. However, the west and the south-facing facades receive the maximum solar radiation during the day, which can increase the building temperature. To optimize the benefits of vertical greenery, south and west facing facades are most effective. Architects need to apply innovative techniques to integrate these factors; for example, using WPC louvers can cast shadows between the panels, providing a favorable environment for plant growth.

Successful implementation further depends on plants selection. Species that are adaptable in extreme environments should be emphasized [10]. The maintenance of vertical greenery is also crucial to ensure aesthetic and environmental benefits throughout the year. Regular care, including pruning, watering, and plant replacing is necessary to prevent deterioration of the system [5]. Although vertical greening may increase risks such as insects and pollen, and careful planning and maintenance can reduce the risk [15].

Policy Implications and Future Recommendations

Finally, the government policies play a vital role in promoting vertical green systems. Countries like Singapore, financial intensive for integrating greenery in buildings, have a positive result in incorporating green features nearly in all new buildings. Similarly, green walls are becoming common in many European countries, driven by policy initiatives. Analysis suggests that policy intervention could make vertical green systems mandatory for specific building types and offer incentives to building owners to accelerate the system [5, 15].

CONCLUSION

The study reveals that natural plants offer pleasant views and comfortable environments, promoting positive attitudes, which are important for the built environment. Vertical green systems, when integrated into building facades, offer multifaceted benefits, including thermal regulation, air purification, biodiversity enhancement, and improved well-being for building users. The case study of the six-story office building in Dhaka demonstrates how a thoughtful combination of WPC louvers and carefully selected plants can address the challenges of urban heat, energy efficiency, and sustainability in tropical climates. Compared to traditional façades, the vertical green façade's initial and maintenance costs are high. Despite this, they are still a cost-effective solution when evaluated through life cycle assessment. This is also notable in how these systems contribute to biodiversity preservation and restoration and provide habitat, food, and shelter for plants and animals such as birds, bees, butterflies, and insects.

To encourage the acceptance of the Vertical Green System, it is recommended that governments and policymakers implement laws to support green infrastructure and the integration of more natural plants in urban settings to enhance mental well-being. Given the long term benefits, governments should also consider offering intensive and subsidies to create a green façade more affordable and economically viable.

REFERENCES

1. Rajak, M.K., R. Kumar, and R. Biswas, Vertical Greenery Systems: a comprehensive review. ICRRD Quality Index Research Journal, 2022. **3**.
2. Jeyasurya T, C.S.R.K., P. Irene Vethamoni, K. Sivasubramanian, M. Djanaguiraman, Green horizons: Exploring the potential of vertical green walls. Plant Science Today, 2024. **11**(4): p. 1055-1064.
3. Ramadhan, A.M. and A.H. Mahmoud, Evaluating the efficiency of a living wall facade as a sustainable energy-saving alternative in hot arid regions. Journal of Engineering and Applied Science, 2023. **70**(1): p. 1-25.
4. Mansor, M., et al., Appreciation of vertical greenery in a city as public. Planning Malaysia, 2017. **15**.
5. Okwandu, A.C., D.O. Akande, and Z.Q.S. Nwokediegwu, Green architecture: Conceptualizing vertical greenery in urban design. Engineering Science & Technology Journal, 2024. **5**(5): p. 1657-1677.
6. Ali Hussein, E. and O. Abbas Abbood. Biomimicry as a sustainable solution in Architecture: Analytical study. in BIO Web of Conferences. 2024. EDP Sciences.
7. Zhong, W., T. Schroeder, and J. Bekkering, Designing with nature: Advancing three-dimensional green spaces in architecture through frameworks for biophilic design and sustainability. Frontiers of Architectural Research, 2023. **12**(4): p. 732-753.
8. Hatipoğlu, Ş. and Ö. Yakın. Effects of Building Materials on Sustainable Facade Design. in Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism-ICCAUA. 2024.
9. Jovanović, D.D., et al., Ventilated Green Facades as a Passive Design Strategy. Innovative Mechanical Engineering, 2022. **1**(1): p. 70-84.
10. Sheweka, S.M. and N.M. Mohamed, Green facades as a new sustainable approach towards climate change. Energy Procedia, 2012. **18**: p. 507-520.
11. Cuce, P.M., et al., Energy saving aspects of green facades: Current applications and challenges. Green Building & Construction Economics, 2021: p. 18-28.
12. Othman, A.R. and N. Sahidin, Vertical greening façade as passive approach in sustainable design. Procedia-social and behavioral sciences, 2016. **222**: p. 845-854.
13. Aldeek, Z.A., Towards efficient green architecture and sustainable facades using novel brick design. International Journal of Design & Nature and Ecodynamics, 2020. **15**(2): p. 205-210.
14. Widiastuti, R., et al. Vertical greenery system as the passive design strategy for mitigating urban heat island in tropical area: A comparative field measurement between green facade and green wall. in IOP Conference Series: Earth and Environmental Science. 2018. IOP Publishing.
15. Leong, B.T., P.S. Yeap, and F.L. Ang. The initial study on implementation of vertical greenery in Malaysia. in IOP Conference Series: Earth and Environmental Science. 2021. IOP Publishing.
16. Al-Kodmany, K., Greenery-Covered Towers: Examining Innovative Design Approaches. 2023.
17. Chojnacka, K., et al., Green urban transition: interdisciplinary insights on green façades design in hot climates as one of crucial strategies for low-carbon development. Clean Technologies and Environ-

tal Policy, 2024: p. 1-21.
18. Lipowicz-Budzyńska, A., Information and message in architecture as a form of social communication. Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska, 2023.
19. Eshrati, P., et al., Analyzing Façade Design in Vernacular Architecture of the City of Bushehr, Iran. International Journal of Architectural Engineering & Urban Planning, 2024. **34**(3).
20. Wang, X., et al., Vertical greenery systems: From plants to trees with self-growing interconnections. European Journal of Wood and Wood Products, 2020. **78**: p. 1031-1043.
21. Lotfi, Y.A., et al., Vertical gardens as a restorative tool in urban spaces of New Cairo. Ain Shams Engineering Journal, 2020. **11**(3): p. 839-848.
22. Coma, J., et al., New green facades as passive systems for energy savings on buildings. Energy procedia, 2014. **57**: p. 1851-1859.