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Vertical Greenery Systems: a comprehensive review

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ABSTRACT: Due to the growth of modern cities, especially in metropolitan regions, the urban heat island has become a significant issue. In an effort to increase urban greenery and provide passive cooling, architects, engineers, building planners, and academics are turning their focus to vertical greenery systems (VGS). Greening the building envelope is not merely a matter of covering the outside of the structure with greenery. Green roofs and walls are often used as decorative elements in buildings. Green infrastructure research and development is growing gradually, deciding aesthetic enhancements as well as environmental, social, and economic advantages. Features like energy conservation, thermal insulation, environmental quality, health, and evapotranspiration underline the critical function of the vertical greenery system. However, these technologies may optimise the functional advantages of plants towards the performance of buildings and contribute to a sustainable urban rehabilitation and retrofitting strategy. Green wall systems design has been a major emphasis in recent years to obtain more efficient technological solutions and better performance throughout the construction process. In addition to lowering temperatures, vertical greenery systems provide other economic, environmental, and social advantages. According to the findings of the literature review, green roofs and facades are essential tools for reducing energy usage and greenhouse gas emissions.

Keywords: Vertical Greenery Systems, VGS, Green Infrastructure

1. Introduction

Buildings often utilise greening structures like green roofs and walls for their visual appeal. There is a modern technology engaged in these systems that may enhance the functional advantages of plants to the building's overall performance [1]. It is also possible to include green systems in an overall sustainable plan [2][3][4]. Urban restoration and building retrofitting [5][6][7]. Green roofs and green walls, when applied to a whole city, allow for the incorporation of vegetation into the urban fabric without taking up any valuable real estate on the street Indeed, when used on a large scale, covering buildings with greenery improves the urban environment by increasing urban biodiversity [1]. The land impact includes [8], stormwater management [9], air quality [10][11] [12], temperature decrease [13] and mitigation of the heat [14][15]. In both winter and summer, vegetation can enhance the microclimate by providing shade, evaporative cooling, and an additional layer of insulation [16][17][18][19][20][21]. In addition, the plant's evapotranspiration may additionally limit its influence on stellar radiation [22], resulting in higher moistness stages and lower exterior temperature than on rigid surfaces [23]. Thermal comfort may be improved and energy consumption reduced by using green wall systems that manage heat gains and losses, according to recent research [3][15][24][25]. Commonly applied terms are 'Green Wall System' [23] [26] [27] [21] [28], 'Vertical Greening System' [29] [30] [18] [31] [32] [2], 'Vertical Greenery System' [27] [33][34][35][36] [17], 'Green Vertical System' [21].

2. HISTORICAL BACKGROUND –Babylon Hanging Gardens, dating about 500 BC, are often considered the first instances of greenery systems [37]. As with Babylon, the Greek and Roman empires used these systems throughout their respective times. In the summer, plants, especially vines, were employed to shade the building exteriors and keep occupants more relaxed and comfortable inside. At the turn of the 1980s, green facades played a critical part in urban ecological development. The bulk of pioneering work on green roofs has taken place in Germany [26]. Between the eighties and the late nineties, roughly 2.5 million square feet of green plants were incorporated onto Berlin's building facades [38]. Currently, Rooftop garden growth in Germany is predicted at 13.5 square kilometres per year [39].

3. TYPES OF VGS SYSTEMS – To describe the most typical construction application of greenery systems, we may say "green roofs" and "green facades." [34].

a) Green Roofs – Roofs make up around 20% to 25% of the total surface area of metropolitan regions. Greening roofs may have a significant impact on both the built environment and the urban environment [41]. A green roof is one that is covered with green vegetation and a growth medium and is sometimes referred to as an eco-roof, a roof garden, or a living roof [37][42]. Several environmental and aesthetic advantages may be gained by using green roofs in urban areas [43]. A few of the advantages include lowering carbon dioxide emissions, cleaning up the air and reducing the urban heat island effect, improving water quality in urban centres, preventing floods by storing extra water, enhancing biodiversity, accumulating native noise levels, and enhancing long-term sustainable growth [43][44][45][46][47]. That green roofs have a significant influence on the thermal efficiency of buildings and the climatic and environmental conditions of interior settings is apparent [46]. Green roofs may minimise heat transfer through a building's roof by as much as 80% in the summer [47]. It is necessary to include plants, growing medium and drainage material, as well as a filter and a root barrier in the design of a green roof [37][45]. According to weight, substrate and maintenance expenses and the plant community and watering needs of the plants, there are three categories of roofs (extensive, semi-intensive, and intense) [42].

b) Green Facades – For the most part, vertical greenery systems are designed with the intention of growing plants on the outside walls of buildings (such as facades, dividers, and blind walls). Some other names for the design include a vertical garden, bio wall, vertical landscaping, and vertical landscape [35] [26]. The green facade and living wall are two different methods that combine to form the green wall. When comparing green facades to living walls, the fundamental difference is that plant grows naturally over the building's outside and creates substrate underneath it. Living walls, on the other hand, employ pre-vegetated plants and cladding structures to cover the building's outside with plants [35] [26] [6]. Green facades, DSGFs, and modular trellis are three types of green facades. Continuous and modular living wall systems are the most common forms, with the primary difference being in the growth material. Using hydroponic methods, plants in continuous systems may be irrigated. Living walls, as previously noted, provide a wide range of plants and make it simple to swap out damaged ones for new ones [30]. Climbing plants are used to cover vertical surfaces in green façades, which are further split into direct and indirect varieties [26] [29][35][48][49].

4. FACTORS AFFECTING THE VGS SYSTEM

Factors affecting the efficiency of the VGS system – According to Domurath and Schroeder [40], a high leaf area index (LAI) per façade unit is required to maximise vertical vegetation's efficiency. This entails improving plant growth control by using pre-grown modules that are easily replaceable, utilising hydroponics techniques to automate the supply of water and nutrients, designing the module with new more robust and lighter materials, and finally, automating any subsequent maintenance activity. Climate, humidity levels, solar radiation, and air velocity all affect the efficiency of greenery concepts. As solar radiation levels rise in the summer, plant cooling mechanisms become less efficient. System design and its components (supporting elements, growth medium, vegetation, irrigation, and drainage) are the focus of the most recent innovations in green walls. As a result, superior technical solutions and improved performance will be obtained throughout the whole building process (installation, maintenance, and replacement).

a) Supporting Elements - As a rule, there is no structural support for a traditional or straight green facade. It is based on the ability to climb plants to hold to the vertical surface. However, if the vegetation covers the whole area, it might be excessively heavy and increase the danger of falling. Galvanised or stainless steel trellises, cables, and wires are the most common support systems for indirect green facades [50][51]. Climbing plants with thick foliage may be held and supported by steel structures and tension cables. Grids and wire nets are ideal for supporting slow-growing plants since they have narrower spacing between plants [52]. The new modular trellises contain a curved grid that adds rhythm and three-dimensionality to the wall's façade [50][51]. There are several various ways to build a modular LWS, such as trays, containers, planter tiles, or flexible bags. Plastic or metal (e.g., aluminium) sheets are often used in the construction of modular trays (e.g., aluminium, galvanised steel or stainless steel) [53][54][55][56][57][58]. It is common for modules to include an interlocking mechanism on the sides so that they may connect to one other. A grid-like front cover may be added to these modular parts to keep plants from falling out. Organic and inorganic chemicals are widely used to create a growth environment for modular LWS, which may then be covered with an inorganic substrate, such as foam, to lower the weight [57][58][59]. The use of geotextile bags to prevent growth medium from coming loose is recommended by several modular LWS. Each plant's growth material may be protected by a bag that covers the whole module [55], or a single bag can be used for each plant [53] [56].

b) Growing Media – Plant roots get their nutrients from the growing medium [56]. When deciding on a growing medium for a green façade, consider the kind of plant and the surrounding environment. Only modular systems need this consideration. It is usual for LWS to use a hydroponic approach because of the absence of a substrate in these systems. Plants may be grown hydroponically, without the need for soil, by utilising screens that are continually moistened by an irrigation system. It is typical for modular LWS to be filled with a growth medium where roots may multiply, which is formed of organic and inorganic substances [59] [57] [58]. Module LWS combines growth media having both light substrate and a granular, expanded or porous substance because of the necessity for excellent water retention [55] [60]. Substrates may be enriched by the addition of organic and inorganic fertilisers as well as metals chelates, nutrition, hormone, and other additives [57].

c) Vegetation – Researchers have employed permanent species [61][62][63], drought-tolerant plants for green walls [26], salt-tolerant plants [64], and natural vegetation [32]. Climate, building attributes, and environmental conditions all have a role in determining the kind of plant that should be used for the green wall. Plants that climb up walls are seen as a low-cost option for vertical landscaping. Evergreen and deciduous leaves are the most common leaf kinds seen on these plants. During the autumn, deciduous plants shed their leaves, whereas evergreen plants keep their foliage year-round. Self-supporting climbing plants include roots climbers, adherent suckers, knotted vines, leaf–stem climbers, leaf climbers, and scrambling plants, which rely on a structure [32] to hold them up. Vegetation under pergolas was a traditional method of shading structures in warm-summer countries [65]. It is feasible to cultivate a greater range of plants in various stages of development using hydroponic systems [65]. In these circumstances, the plants are chosen based on their visual appeal [65][66]. Plants that need less watering (such as native species) and are well-suited to the climate and exposure (such as sun, semi-shade, or shadow) of the area are best for achieving long-term sustainability. Instead of perennials and shrubs, modular LWS now provides succulent carpets. Succulents [10] may be used to minimise the amount of water needed for irrigation. Vegetables and fragrant herbs may now be included in green facades, either as planters or containers, via the use of continuous LWS [67] or modular LWS [68] in new designs for green walls. Plants used in green walls are generally evergreen because of the relevance of the façade's thermal behaviour [69].

d) Irrigation – Irrigation requirements vary depending on the kind of system, plants, and climate. Irrigation water may be added with nutrients, fertilisers, ions, phosphorus, amino, or horticultural materials to promote plant development. The irrigation tubing may be inserted into a recess on the upper side of certain modular LWS trays. Gravity-fed watering holes are included in the trays' recesses [53] [54] [56] [57]. Excess water may be irrigated via drainage holes on the bottom of the trays. A variety of materials may be used to make irrigation tubes and connections that have varying outputs that can be suited to the plant's irrigation demands. Techniques for decreasing the quantity of potable water used are also mentioned by certain LWS. We may employ techniques like capturing and reusing rainfall [55] from building roofs, recycling wastewater collected in drainage systems [67], and monitoring our water use with sensors [70] [67] and other devices to regulate the quantity of water collected in tanks [54]. Gutter installation in the system base is also referred to in other LWS either modular [68][71] or continuous [70] [67]

e) Drainage – Gravity is used to remove excess liquids from green walls. Geotextiles are used in both continuous and modular LWS to promote permeable membrane drainage while inhibiting root growth. For better drainage, a modular system's bottom might be curved, slanted, perforated, or porous [54].

Sand or other ways for filtering rainwater [72] and granular inert filler [66] are examples of filters that are used in containers to help drainage and root development [73]. In order to promote ventilation and remove pollutants and moisture from a substrate, modules may be built with holes or pores on their sides and backsides [55][58].

5. INFLUENCE OF THE VGS SYSTEM

a) Energy Consumption – Greenery systems are one of the most cost-effective and environmentally friendly retrofits for building envelopes that may be used to decrease heat absorption. Green roofs have been shown to reduce the heat from structures by 70–90% in the summertime and 10–30% in the wintertime, respectively. Researcher [73] shows that green rooftops may decrease temperature input and energy loss by 95 percent and 26 percent over twenty-two months. On a bright, sunny day, another study revealed that installing vertical vegetation systems reduced peak cooling loads transmitted via walls by 28% [74]. Greenery surfaces are also said to absorb roughly 70% of the sun's rays. The shadow effect, which is perhaps the most important in terms of energy savings, is primarily due to the solar radiation interception supplied by plants. Using flower pots around the outside of a structure may also serve as an active method for reducing energy use. It was found that at 15 h, the exterior surface temperature was reduced by 13 °C, while the inner surface temperature was reduced by up to 11 °C. Thermal transmission and energy usage have been reduced significantly. A 10 cm vegetation roof reduces heat transfer by 59% and 96% respectively, and energy consumption by 31% and 37% [75] when compared to a concrete roof. With its capacity to lower temperatures, green building systems may help decrease cooling energy use and improve the energy efficiency of a building. The west-facing wall gets 189 watts per square meter of solar energy. Solar energy received by the plants is 133 W/m^2, and the remainder of the radiation goes through the leaf layer without being reflected. When using a double-skin green facade, an air conditioner's power consumption is reduced by 20%, depending on the vegetation's qualities. Additionally, it has been shown that a 0.5 °C drop in room temperature may save power use by 8 percent [76].

b) Living Comfort – Upto 6 °C of indoor temperature decrease and a 15% increase in the indoor relative humidity were obtained [77]. According to research [78], Green walls offer substantial potential as a sound insulation strategy for structures. Plants' ability to reduce background noise by absorbing, diffracting, and reflecting sound has been shown in several earlier investigations [79][80][81][82][83]. Green walls have been shown to boost people's subjective health by reducing harsh noise discomfort.

c) Environment Quality – The decrease of the heat island effect is one of the goals of VGS. Additional airflows are produced by expanding urban green spaces, allowing hot air to ascend fast and be replaced with fresh air from green regions. In Vienna, research has shown that urban vegetation has a significant influence on the function of cooling in structures and, as a result, on the cooling of such structures [84]. Studies have shown that plants' well-known ability to purify the air they breathe by filtering pollutants in their leaves may be used in vertical greening systems [85] [86] [87]. There are several environmental advantages to using a vertical vegetation system. for example, collecting dirt and filtering the air [88][89].

d) Evapotranspiration Effects – Plants and substrates evapotranspiration water, which cools the surrounding environment. Evapotranspiration may help reduce energy consumption and improve air quality via the evaporation of water vapour [90]. Evaporation and transpiration make up evapotranspiration. Evaporation is the process through which soil water evaporates into the atmosphere. To cool the medium, long-wavelength radiation (400–700 nm) is absorbed by leaves.

Excessive heat may also be released by convection and evaporation [91]. In both humid and dry situations, humidity is critical for maintaining proper body temperature control. Evapotranspiration is responsible for 58 percent of heat loss, whereas long-wave radiation exchange accounts for 31 percent of heat loss and 1.2 percent of heat transmission into a building from a green roof, according to China's summer climate model [92]. Due to evapotranspiration, a wet green roof loses heat two times as much as a dry green roof. A dried rooftop garden reduces heat entering a building by around 60% compared to a standard roof [92][93]. As a result of evapotranspiration, hot weather absorption into the structure is significantly decreased, therefore reducing the cooling demand of structures [5]. Green roofs' cooling benefits are primarily due to evapotranspiration and its important function in reducing the amount of solar radiation that enters the structure.

e) Health – When it comes to human comfort, the temperature is the most important factor [94]. Office workers, particularly those who conduct reading, typing, and mathematical analysis duties, benefit from better air quality because of its health-improving effects [95][96]. Contact with nature has a positive influence on health and well-being as well as a positive psychological impact [97][98]. The presence of green spaces also helps to decrease stress and obesity [99]. The psychological and physiological well-being of residents may be improved by enhancing the quality of the interior environment [100][101]. Urban greenery areas may be produced by installing green systems in urban dwellings [102]. Extreme heat stress has a significant impact on health. According to studies, extreme heat, including a rise in the minimum daily ambient temperature from 20 ° C to 30 ° C, raises the death rate in the elderly (those over 65 years old). The quality of sleep of those who live in hot environments is similarly impacted [103]. The excellent visual quality of the natural environment has been found to relieve stress-related psychosocial symptoms [98] [104].

f) Carbon Emission – It [105] emphasises the plant's potential to turn CO^2 emissions from transportation or heating into carbon hydrates and oxygen. Due to increased carbon sequestration, plants with a more significant percentage of woody stems are desirable for green walls [106]. Furthermore, plants use carbon dioxide as a source of energy and release oxygen via photosynthesis [107][108][109]. Because they use less energy and use atmospheric carbon in the photosynthesis process, the horticulture system has a significant influence on the reduction of greenhouse gas emissions. A considerable reduction in CO^2 emissions may be achieved while saving 2.65 MW/h x 106 each year via the usage of vertical greenery systems, according to research. In the United States, a medium-sized mature tree may decrease CO^2 emissions by around 133 kg per year, according to the US Department of Agriculture [76]. Carbon dioxide consumption increases in the morning and peaks around midday. The CO^2 concentration in the atmosphere is highest at night when the sun sets, and the quantity of CO^2 reduces fast. Greenery systems are effective in assimilating carbon into the environment and stabilising carbon emissions. The absorption of carbon dioxide from the environment reaches its peak during the vegetative stage of plant growth [30].

g) Social Benefits – The considerable potential for reduced UHI concerns by decreasing wall temperatures as a result of shadowing and evapotranspiration has been verified by green walls [110]. Blackbody radiation emitted by a hypothetical spherical enclosure would have the same net transfer of energy with the body as the real complex environment, despite the enclosure's uniform temperature [111][112][113][114]. Using green walls to integrate vertical construction structures into the landscape is a great way to enhance landscape beauty and minimise environmental impact [115][116].

h) Sustainable Development – The entire environmental load may be significantly affected by changes in the types of resources used, their strength, reprocessing possibilities, flora durability, and liquid usage [117][118]. Using vertical vegetation systems as window shades is one option [119]. There are several benefits to using vertical greenery systems, such as increasing sunshine and minimising glare [120]. There is no other vertical greening method that seems to be economically feasible in all conditions than the green walls façade, thanks to the low costs of installation, maintenance, and removal. Indirect green facades, on the other hand, are more expensive to build and dispose of due to the complexity of their supporting structure. Planter boxes also have higher costs because of the support and watering system that must be installed. These negatives may be mitigated by using sustainable solutions, such as the use of greenery systems and the incorporation of these systems into buildings [94].

6. COST COMPARISON REVIEW FOR VGS SYSTEM – Green facades are more environmentally and economically friendly [121] [117]. These systems have a minimal impact on the environment due to the lack of materials and the low level of maintenance they need. Additionally, the cost of green wall systems may have a major influence on the choice process. Green facades, whether direct or indirect, may be constructed for less than 6,190/m^2 [117]. Depending on the kind of material utilised, the cost of a modular green façade might range anywhere from four to eight times higher than the cost of an HDPE-based facade. When it comes to evaluating the economic viability of vertical greening systems, Perini & Rosasco [29] presented a Cost-Benefit Analysis (CBA). The biggest concern with green roofs and facades, according to Francis and Lorimer [8], is the ongoing maintenance and investment expenditures, as well as challenges related to their installation. As a result, experts like Feng and Hewage have addressed the necessity of cost-effective vegetation systems [73]. The thermal efficiency of a building improves with the use of a complete green roof, resulting in an energy savings of about 16,388/year.

7. CONCLUSION – Vegetation may be grown on any vertical surface, including walls and roofs. When severe sun radiation is blocked, and the natural cooling properties of plants are used, temperature is reduced. Plants decrease the amount of solar energy absorbed by the atmosphere, which lowers the temperature. A building's capacity to run and function at a low energy consumption may be achieved via the cooling effects of vertical vegetation systems. To produce a high shadow rate with vertical greenery systems, special attention must be paid to the selection of appropriate plants and leaf area index features. In many cases, a continuous solution is more compact than a modular one. Nevertheless, the majority of current advancements in green wall system design centre on modular systems, which provide installation benefits, making it possible to quickly cover a large area and simplifying their maintenance by allowing each component to be disassembled and replaced individually. Thus, future VGS research should include the linked components and how they impact both cost and performance. Although there are few studies and research on the combination of ventilation and vertical greenery systems, it is possible that these systems may lower temperatures. Research on the material used for green facades and living walls, as well as the substrate that holds them, is the greatest method to increase thermal efficiency. Any VGS project, no matter how big or little, must have a clear understanding of how the system works and be willing to embrace the intricacies and possible drawbacks that come with it.

CONFLICTS OF INTEREST

There are no conflicts to declare.

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