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Decoding the Implementation Strategies of Vertical Gardens in Public Spaces – Valuable Lessons from Case Studies

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Abstract
Urban heat islands (UHI), air pollution from industrial and vehicle emissions, and the loss of green spaces contribute to a decline in biodiversity, and excessive stormwater runoff because of impermeable surfaces are some of the serious environmental issues that urban regions confront. These challenges exacerbate health concerns, societal deterioration, ecosystem damage, and the greater danger of flooding. India's population growth has destroyed metropolitan green - compared to the UN-recommended standard of 9m^2 of green space per capita, Chennai and Mumbai have a meagre 0.46 m^2 and 0.12 m^2 of green space per capita, respectively. The extensive use of vertical gardens in various locations appears to be an innovative strategy to address some of the most pressing issues. Vertical gardens can be an alternate strategy for increasing urban inhabitants' contact with vegetation, which has been demonstrated to be helpful for overall psychological health. But problems like constant maintenance difficulties, exorbitant expenses, and a lack of knowledge about vertical gardens are leading people to believe that they are only for aesthetic reasons, and halting the growth of applications. This research evaluates various international case studies as a diagnostic tool to identify multiple approaches to evaluate vertical gardens in public spaces advantages and demonstrate their importance for urban settings, especially for increasing energy efficiency and ensuring sustainable development.

Keywords: *Vertical gardens, case studies, pollution, sustainable development, Mexico, Australia, India*

INTRODUCTION

Motivation

Vertical gardens, also commonly referred to as "green walls," are essentially defined as walls that possess a remarkable layer of lush vegetation (Shaikh, Gunjal, & Chaple, 2015). Throughout India, numerous municipal corporations have taken the initiative to showcase their admirable efforts through structured environmental activities. Today's society has been driven by the rapid and exponential urbanization accompanied by continuous surge in population where cities are growing geographically beyond pre-defined boundaries and outpaced its capacity which has inevitably resulted in the deterioration of our environment and the reckless depletion of natural resources (Marcotullio, Keßler, Gonzalez, & Schmeltz, 2021). This menacing environmental transformation poses a formidable challenge to the overall well-being of humanity across the globe. It's a threat to our carefully interlinked social and economic systems. Particularly in developing nations, urbanization has inflicted even serious environmental upheaval.

As cities burgeon and sprawl, their once-pristine ecosystems undergo such drastic metamorphosis that they barely resemble their original, untouched states. Vast stretches of natural landscapes, teeming with native flora and fauna, have been unceremoniously displaced by a plethora of artificial materials, such as cold, unyielding steel, unrelenting concrete, and pliable yet enduring plastic, which now reign supreme as the primary constituents of urban civilization. Alarmingly, more than half of the world's population currently calls cities their home, with projections forecasting a staggering 60% augmentation in built-up areas by 2030, encompassing an overwhelming 1.5 million km^2 on a global scale (Henderson & Turner, 2020). According to current estimates, anthropogenic activities are to blame for the 1°C rise in global warming (Allen, M.R et al. 2018) . Stated differently, global CO2 emissions must drop by 45% between 2010 and 2030 and reach zero by around 2050 in order to keep warming to 1.5°C (UN, 2017). Numerous pollution-related issues have arisen in cities with a growing vehicular population, exponential

growth of industries, and urban heat due to concrete structures. Air pollution accounts for 35% of premature deaths in India (Pandey, 2019).

Significance of the study

To ensure efficient environmental performance, sustainability, and liveability of cities, retrofitting existing infrastructure is required. The development of ecological energy-efficient and resource-conserving building technologies is also necessary (Zarębа, Krzemińska, & Kozik, 2021). Urban green infrastructure can mitigate the adverse effects of urbanization. The quality of green areas has enormous social, economic, and environmental benefits. The International Panel on Climate Change has recognized that green and blue urban infrastructure components have the potential to satisfy multiple goals, as outlined in the SDG's and are very successful in lowering city air temperatures. Green-blue-grey infrastructure (GBGI), which includes vegetation-based (green = trees, grass, hedges, etc.), water-based (blue = pools, ponds, lakes, rivers, etc.), and engineered (gray = green walls, green facades, and roofs) structures, has been widely proposed to mitigate the impact of urban overheating and decrease energy consumption (Zonato et al, 2021) . Vertical gardens, façades covered with living plants and related growing systems, can offer a specific and attractive approach to the diffuse green dimension of cities. Vertical gardens provide low-cost solutions to removing airborne particulate pollutants present in great quantities in densely populated areas (Santamouris & Osmond, 2020). Vertical gardens or living walls are structures made using plants that clean the air, retain moisture, and lower temperatures in urban habitats. Additionally, it plays a crucial role in biodiversity preservation and provides habitats to accommodate birds and insects, manages stormwater by absorbing excess rainfall, and enhances urban aesthetics. It can be done by embedding nature within cities; that's the reason BGI design enables cities to reduce their environmental impact and support a harmonious co-existence. Building an ecosystem is essential for combating climate change and is very important in today's world (Bader et al, 2022). Studies demonstrate that vertical gardens positively impact residents' mental well-being and quality of life (Urbano, S Akkawi, Brînzac, & C Savoia, 2024).

Objectives

- To understand the importance of vertical gardens through various case studies
- To explore the successes of vertical garden initiatives that are incorporated into public spaces in Mexico and Australia, demonstrating their social, economic, and environmental benefits.

Background and Rationale

Urbanization in Indian cities has brought many environmental challenges that demand immediate attention. Air pollution, primarily caused by vehicular emissions, industrial activities, and construction dust, poses a grave health hazard for the urban population. One of the most prominent challenges is the urban heat island effect. A study by the Centre for Science and Environment (CSE) between January 2001 and April 2024 reveals alarming findings about rising humidity and temperatures in six Indian megacities: Delhi, Mumbai, Kolkata, Hyderabad, Chennai, and Bengaluru (Banerjee, 2024). They experience high temperatures, specifically during the summer months. The rapid urbanization, extensive concrete structures, and limited green spaces contribute to the absorption and retention of heat, creating localized pockets of significantly higher temperatures within the urban areas compared to the surrounding rural regions (Edeigba, Kanayo, Aniekan, Preye, & Andrew, 2024). This phenomenon exacerbates heat stress, increases energy consumption for cooling, and poses health risks for the urban population.

Countries like India and Mexico, in particular, have gained international attention for their severe air quality problems. Emissions from vehicular traffic, industries, construction activities, and biomass burning contribute to high levels of particulate matter, volatile organic compounds (VOCs), and other pollutants in the air (Thakur, 2024). This not only poses serious health risks but also worsens the urban climate by trapping heat and reducing the quality of the air residents breathe.

Moreover, the rapid urban expansion has led to encroachment upon green spaces, resulting in loss of biodiversity and degradation of ecosystems. The hour needs to implement sustainable and holistic strategies that promote green infrastructure, efficient waste management systems, and renewable energy sources. By integrating environmentally conscious urban planning, improving public transportation,

promoting sustainable practices, and raising awareness among citizens, Indian cities can mitigate the environmental challenges they currently face, ensuring a healthier and more sustainable future for all.
Urbanization induced a decline in vegetation and has significant implications for people's quality of life (Bustami , Belusko, Ward , & Beecham, 2018). Vegetation is critical in sustaining human life, offering numerous benefits such as enhancing air quality, regulating temperatures, recharging groundwater, and promoting mental well-being. However, rapid urbanization and city expansion often result in an inevitable reduction in green spaces, highlighting the urgent need for integrating vegetation within existing urban structures. The additives used in the vertical greenery systems are found to be toxic and are not sustainable for vegetation. Natural substrates that do not affect vegetation and other biotic and abiotic factors should be included in the system (Pérez, Coma, Martorell, & Cabeza, 2014). The study aims to evaluate the design features, practical implementation, and feasibility of vertical gardens in public spaces, and propose cost-effective strategies for their successful implementation. The perceived key challenges include construction complexities, plant selection, and maintenance, which are crucial to ensure long-term success. This research also investigates the efficacy of vertical garden strategies adopted in the various pilot projects to assess environmental benefits as it is a low-cost technology.

LITERATURE REVIEW

Incorporating living vegetation on vertical surfaces enhances aesthetics and serves crucial environmental roles. Vertical gardens positively impact air quality by reducing pollution and noise, creating serene spaces for individuals. The characteristics of plants influence the amount of absorption. Vertical gardens are more effective than street trees at reducing air pollution, particularly in an urban context, due to their ability to more effectively and quickly move air pollutants (Perini, Ottele, EM, & Ralteri, 2011).
They also increase urban biodiversity, supporting native plant species and providing bird habitats, thus promoting wildlife conservation. However, maintaining these gardens requires significant dedication, horticultural expertise, and attention to environmental conditions. The material used in the framework determines the classification of vertical gardens. Four types have been commonly used to examine vertical garden frameworks: systems based on mineral wool, felt layers, modular systems, and foam systems (Kanter, 2014). To develop media, water systems, plant nutrition, and general reflections for green dividers with adaptable plants, a vertical garden framework should be established using appropriate structures and parts and careful planning and execution.
Vertical gardens are essential to innovative city initiatives, fostering sustainable development that addresses environmental, economic, and equity issues. Vertical gardens composed of live plants exhibit seasonal responsiveness, contributing to the thermal regulation of built environments. In winter, they facilitate solar gain; in summer, they provide shade through vegetation, enhancing microclimate conditions via natural ventilation and evapotranspiration. Fig. 1 shows the history of Vertical gardens Since the 6th century BCE.

5.1 History of Vertical Gardens

6th century BCE

- Hanging Gardens of Babylon, Mesopotamian
- These hanging gardens which are a precursor to vertical gardens are considered seven wonders and were implemented by King Nebuchadnezzar II (Rameshkumar, 2018)
- Notable for their monumental scale and astonishing feat of engineering and horticultural mastery of the time. They used advanced irrigation and soil management techniques.

Between 3rd Century BC and till the end of 17th century	• Under Roman horticulturists, the custom of training vines and vertically climbing plants on trellises and villa walls developed ivy, roses, honeysuckle, grapevines and other creepers were carefully cultivated as ornamental additions for centuries in aristocratic and monastic residences (Asik & ArunKumar, 2024)
Beginning of 20th century	• Stanley Hart White, a professor at the University of Illinois, received a patent in 1938 for his creation of "Botanical Bricks," which served as a model for mod ular Tray systems that allowed plants to be grown hydroponically into whole vertical ecosystems (Richard, 2012). • Evolution of integrated vertical garden system
1986	• French scientist and innovator Patrick Blanc transformed the idea of vertical gardening by erecting his first hydroponic plant wall at the Museum of Science and Industry in Paris (Blanc, 2008). • Blanc discovered the idea of building entire vertical ecosystems, which are soil-free structures in which plants can be anchored in fibrous material and automatically hydrated by water circulation systems. • He established vertical gardens as a revered art form and architectural wonder that can transform sterile indoor spaces into lively, oxygen-producing natural havens with his famous installation at the Musée du Quai Branly in 1988 (Rameshkumar, 2018)
1986 -2000	• Blanc's vertical garden concept quickly gained traction in the 1990s and early 2000s by adopting new modular systems and techniques. • These innovations greatly expanded the viability and adaptability of vertical gardens in urban areas, resulting in some of the first significant public installations, such as: • Canada's largest indoor bio-filtration living wall at Toronto's Canada Life Building (1994) and California's Universal City Walk (1993) (Prescod, 2015). • Innovations include: Cable Trellis System, Stainless steel wire rope cable mesh and Modular trellis panel system.
21st Century – Vertical garden as an Adaption strategies for Environmental Containment Sustainable Architecture	• Green wall exposition - Most iconic vertical garden projects are Milan's Bosco Verticale (Vertical Forest) Twin Tower Project (Wang, 2020) and the living green walls inside Singapore's gorgeous Bay South Garden. Major revolutionary ideas include: • Modular Hydroponic systems manufactured from recycled materials (Kennard, 2020). • Biochar based filtration systems greywater treatment • Solar Powered self irrigation systems for outdoor vertical gardens

Fig. 1 History of Vertical Gardens (Source: Author)

Impact on Energy Consumption and Public Health

The urban climate and thermal challenges of Indian cities have a significant impact on energy consumption and public health in general. These challenges contribute to increased energy demand for cooling and have adverse effects on the well-being of city residents.

Firstly, the high temperatures and urban heat island effect lead to a surge in energy consumption for cooling purposes. As cities experience soaring temperatures, residents heavily rely on air conditioning to maintain comfortable indoor environments. This increased demand for cooling places a significant strain on the electricity grid and amplifies energy consumption, leading to higher greenhouse gas emissions and contributing to climate change (Meena, et al., 2022). Addressing the urban climate challenges through sustainable urban planning, incorporating green spaces, and promoting energy-efficient building design can help reduce energy consumption and dependency on cooling systems.

The urban climate challenges also have profound implications for public health. Heatwaves, exacerbated by the urban heat island effect, pose a significant risk to the well-being of individuals, particularly vulnerable populations such as the elderly, young children, and those with pre-existing health conditions. Heat-related illnesses, including heat exhaustion and heatstroke, are becoming more prevalent during extreme heat events (Elliott, Eon, & Breadsell, 2020). Additionally, prolonged exposure to high temperatures can result in dehydration, respiratory distress, and cardiovascular problems. Mitigating the urban heat island effect by implementing green spaces and providing shaded areas can help alleviate the health risks associated with extreme heat.

Air pollution, another consequence of urbanization, has severe implications for public health. The elevated levels of particulate matter, nitrogen dioxide, sulfur dioxide, and other pollutants in the air contribute to respiratory problems, cardiovascular diseases, and other health issues. Delhi, in particular, has been known to experience severe air pollution episodes, with long-lasting impacts on the health of its residents (Bikis, 2023). Efforts to reduce air pollution through stricter regulations, the promotion of cleaner transportation, and industrial practices are essential to improve public health and mitigate the associated health risks.

Furthermore, urbanization's lack of green spaces and limited opportunities for physical activity contribute to sedentary lifestyles and an increased risk of non-communicable diseases such as obesity, diabetes, and mental health issues. The integration of green spaces and recreational areas in urban planning can encourage physical activity, promote mental well-being, and provide spaces for social interaction and community engagement, thus positively impacting public health.

To address the impact on energy consumption and public health, sustainable urban planning approaches are crucial. This includes the incorporation of green infrastructure, energy-efficient building design, promotion of public transportation and non-motorized modes of transport, and stricter regulations for industrial emissions and waste management. Additionally, public health initiatives such as awareness campaigns, access to healthcare facilities, and the provision of safe and inclusive urban environments can significantly improve the overall well-being of city residents.

Benefits of Vertical Gardens

The versatility of vertical gardens makes them ideal for both indoor and outdoor environments. From private homes and schools to public buildings and transit centers, vertical gardens can be integrated into a variety of urban settings and enhance their aesthetic appeal. An eco-friendly subway station with lush green walls would make the daily commute more energizing, thereby improving our quality of life.

Temperature variations can cause a variety of phenomena as thermal effects on buildings. Depending on the material, high temperature variations may cause structures to expand or contract. These potential movements develop drafts, leaks, deformation, and structural failure over a period of time. Systems for vertical gardens will reduce expansion and contraction, which will lessen the effect of temperature variations on building facades. Thus, they shield structures and influence the performance of the building materials, leading to long-term durability (Tabassom, Abdullah, Ossen, & Mohammad,, 2014). The advantages of a green-living wall in a workplace inlcude cooling effects, reductions in carbon-di-oxide emissions and energy saving properties. A vertical hydroponic wall with an area of 15 m^2, located within a 140 m^3 office environment, has shown notable environmental advantages. When ventilation is utilized,

it can achieve a net cooling effect that ranges from 2.5°C to 4.5°C; without ventilation, the temperature drop is between 1.2°C and 3.6°C. Furthermore, the system enhances indoor air quality by lowering CO_2 levels by about 5% to 50%, based on the type of plants used. This green wall also promotes energy efficiency, resulting in an estimated yearly energy reduction of around 20%, which translates to approximately 1,400 kWh annually (Yungstein and Helman, 2023).

Vertical gardens, or green walls, consist of vegetation and soil structures that can be applied on larger scales, including railway station walls and industrial facilities. They mitigate heat from these structures while providing habitats for diverse life forms. Various plants, such as shrubs, grasses, and flowering species, can adapt to different climates, and with easy irrigation systems.By bringing people closer to nature, vertical gardens boosts mental and physical health while promoting a sustainable relationship with the environment. [1]Through this design approach, spaces are crafted to promote relaxation, increase productivity, and nurture a sense of harmony with the natural world. The goal is to foster spaces that benefit both humans and the planet by integrating nature thoughtfully and effectively into built environments

As urban planners often overlook vegetation solutions due to a perceived lack of profitability, incorporating plants can enhance health by purifying air, improving aesthetics, creating micro-climates, and enhancing property values.

Successful Case Studies: International and National

7.1 Case Studies (International)

7.1.1 Case study 1: City Level Project: The Vertical Gardens of Mexico City Highway

Fig 2: Mexico City highway pillars and Wildlife are not left out as birds find a perfect nesting place (Source: (Myada, 2020))

The idea of the Mexico City Vertical Garden, popularly called "Via Verde" (Green Way), is a citizen-led initiative and the biggest urban gardening project to mitigate high levels of pollution and to tackle the city's green area deficit (Perrone, 2020). The six pollutants—ground-level ozone (O_3), carbon monoxide (CO), sulfur oxides (SO_x), nitric oxides (NO_x), lead, and particulate matter—are used by the Índice Metropolitano de la Calidad del Aire (IMECA) to report daily air quality. Scores in the range of 101–150 reflect atmospheres that are unhealthy for sensitive populations, such as young children and older adults with underlying cardiac or pulmonary disease; scores of 151–200 indicate air considered harmful to the entire population (Borbet, Gladson, & Croma, 2018).

Concept: The plan is to build 60.000 square metres of vertical gardens on 1000 highway columns in order to address the city's green space shortfall and lower pollution levels.Via Verde's main propositions are to provide oxygen to 2500 people, filter 27,000 tons of gases, capture 5000 kg of dust and to process more than 10.000 kg of heavy metals (MND, 2019).

The Inception of the Project: 2019. The project is designed by architect Fernand Ortiz Monasterio from Verde Vertical, a leading vertical garden construction company. Via Verde which was inspired by a Change.org petition with 80,000 signatures in 2016, gives Mexico city a lush facelift by turning highway pillars into vertical gardens (Popescu, 2016) .

Guidelines: Mexico City's Ministry of Environment (SEDEMA) announced significant strides in the city's reforestation initiative, showcasing the creation of 16 vertical gardens. The project is funded through sponsorship (AIPH, 2024).
Vía Verde offers its sponsors advertising space on every tenth pillar in return for financial support.
Contextual Setting: Mexico city's rapid expansion and high population density have critically impacted its urban liveability and sustainability with severe air pollution. The problems of air pollution is compounded by its unique geographical basin location that traps pollution and a high volume of vehicle emissions which significantly contribute to urban heat island.

Scale	City and Country	Year	Issues	Vertical Garden Approach	Outcomes	Direct Benefits
City Level	Mexico City, South America	2019	In 1992, the United Nations described Mexico City's air as the most polluted on the planet (IDRC, 2011). Enormous traffic and high volume of vehicle emissions (3.5 million vehicles daily congest the city (IDRC, 2011) with 75% of air pollution) Spatial constraints and Scarcity of open areas due to urban sprawl	The project includes the installation and maintenance of more than 40,000 m^2 of vertical gardens in more than 700 columns along the Periférico highway, which encircles the central city (Menezes, 2018) Diverse plant species generate oxygen, absorb pollutants, and dampen traffic noise. Since the vertical gardens are superimposed on top of prefabricated metal frames, their installation will not impact the pillars' structural integrity Several auxiliary metal rings will be used to secure the frames to the pillars. (Fig.2) Instead of soil, the plants will grow on a hydroponic textile which has a unique density that enables the roots of the plants to interweave with the fabric (Kennard, 2020). The cloth is made from recycled plastic and has the same density as soil . The plants will be kept in the best possible condition by an automatic rainwater watering system that can be remotely monitored using GSM.	Mitigate severe pollution and reduce urban heat island. Response to growing deficit of green areas per capita. Twenty-five thousand people get their oxygen from the plants. Consequently, the project has positive effects on the environment and public health in addition to its aesthetic value. Reduced the stress level among the commuters who frequently	**Environmental** **Social** **Economical** **Technological**

					use the highway. Improves the psychological well-being of the community. Employment is positively impacted by the initiative: 750 jobs were indirectly created by the project, and 250 people are directly employed at Vía Verde (Truelsen, 2019). The bags containing the plants are made by 100 community service volunteers. This worlds largest urban green project has unique innovation, mainly in locally developed technologies. sensors in every garden is equipped in real time,	

					and they constantly transfer data concerning water, light, temperature and nutrients. Plants species like Aptenia Cordifolia, Peperomia obtusifolia which have low water consumption and are known for their high strength to sustain for longer term	

Case study 2: City Level Project: The Minhocão Viaduct – Hanging Garden, Sao Paulo

To counter the grayness of São Paulo and to transform the derelict areas under the elevated highway, Triptyque has proposed lining the viaduct with dashes of greenery and vegetation to create vibrant hubs of activity that are lively, pedestrian-friendly, and welcoming (Malone, 2016). They also envision a community engagement space for sports, special events and also for artistic expression. The firm intends to incorporate the idea of color and dynamism as the key components of the project.

Fig. 3 View of Minhocão viaduct (Source: inhabitat.com)

Concept: The plan is to suspend air-cleaning plants beneath the nearly two-mile-long Minhocão viaduct **(Fig.3)** (Jewell, 2016). The vegetation could be an effective way of curbing emissions, and the initial

positive effect of the project was the high oxygen-producing plants filtered 20% of CO_2 emissions from automobile traffic.

The Inception of the Project: . The project was unveiled by Triptyque Architecture, a Franco-Brazilian Firm in collaboration with landscaper Guil Blanche, aims to convert the long dark unattended Minhocao viaduct under section into a vibrant public space with hanging garden.

Contextual Setting:

The minhocão viaduct, an elevated expressway built in 1971 in São Paulo, Brazil, during a period of rapid growth that passes through the center, sought to improve the car connection between the east and west part of the city (Williams, 2024). The highway was supposed to ease traffic congestion and help the city foster its expanding population

Scale	City and Country	Year	Issues	Vertical Garden Approach	Outcomes	Direct Benefits
City Level	The Minhocão Viaduct – Hanging Garden, Sao Paulo, Brazil	2016	The minhocão viaduct, an elevated expressway built in 1971 in São Paulo, was depressing, full of visual clutter, and an eyesore that plagues the majority of downtown (Sayer, 2016)	High motorized traffic along the Minhocau viaduct is the major contributor to rising externalities, vehicle emissions, and noise. The project exemplifies two architectural interventions. first, the viaduct with an array of vegetation and parks. To transform a dark, depressing highway underbelly into a thriving urban space (Alice, 2017). It involves providing bountiful natural light under the viaduct while incorporating a natural water harvesting system to irrigate the plants, and the residual excess water will help clean the Marquise surface and surrounding surfaces.	The repurposing of spaces beneath the elevated viaduct foster a community engagement and identity to one's proximate environment. It creates a positive psychological effect. It reduces traffic noise and choice of plants for its air-cleaning qualities. The architects intend to open the covered area as much as possible to provide the optimum quantity of natural light to maintain the ultra-green design.	**Social** **Environment**

Case study 2: Neighbourhood Level Project: Vertical Garden Green Sculptures - QEII Supreme Law Courts– QLD, Australia

Concept: The Brisbane Magistrates Court is interlinked to a landscaped public square by the new court building, which forms a distinctive legal enclave. It covers the floor space of approximately 65,000 square meters over 19 floors. Apart from aesthetic appeal, this striking feature of green columns to the courtyard reduces heat gain and reduces the cooling loads.

Cost of the Project: $570 million

Client: Department of Justice & Project Services

The Inception of the Project: 2008 -2012

Contextual Setting: The Brisbane Supreme and District Courts are considered one of Australia's largest court systems. This legal precinct is bounded by Roma, George, and Herschel streets and completes an entire city block with a new public square off the main entrance. Designed by lead designers Architectus Brisbane in collaboration with Guymer Bailey Architects, the project was won after a design competition

Scale	City and Country	Year	Issues	Vertical Garden Approach	Outcomes	Direct Benefits
Neighbourhood Level	Queensland, Brisbane Australia	2008 -2012	Brisbane's sub-tropical climate (Climate zone 2) is warm, humid, and generally mild, with dry winters. It is characterised by warm sunny days throughout the year.	The building has a double-skin glass facade with integrated screening and glass fritting to achieve shading and light control. Vertical garden trellis spans approximately 20 meters between Level 12 and level 17. The sculptures are constructed with three cable clusters braced by staggered stainless steel rings. One cable has a precisely arranged timed water system. Nets and mesh were used to make trellis structure for vertical gardens in the tightest building envelope. In addition to provide shade, green wall systems were used to reduce the effect of the urban heat island improves microclimate and increase indoor comfort. Making full use of natural light, the public spaces, courtrooms, and private offices open up to these double facade courtyards and creates a spatial dynamics by blurring the indoor and outdoor environment.	Increase the productivity of the employees. It reduces Energy consumption	**Social** **Environment**

and provides a dramatic shift from traditional court design.

Case study 3 : National Level - Node level Project: The Ludhiana railway station, India – Vertical Gardens (Fig.4)

Concept: To reduce the use of plastic, over 2,000 waste plastic bottles were placed on the walls of platform number 1, and add more greenery to the Railway station the initiative was initiated to curb

pollution and make the area more lively and vibrant by adding the aesthetic components (Sukheja, 2020). One more reason why the railway station should be beautified with vertical gardens is that many more people pass through a railway station compared to those who visit a public park.

The Inception of Project: The project was inaugurated on Income Tax Day on July 24. This unique proposal is the brainchild of Rohit Mehra, an Internal Revenues Services officer (No author, 2018).

Contextual Setting:

It is the first railway station in India to initiate the idea of vertical gardens to provide aesthetic appeal and a green ambiance to add a touch of nature to the urban environment. To create a sustainable and aesthetically visually appealing environment they incorporated eco-friendly design features and lush green spaces. It covers an area of 10,135 square feet and has also found a place in the Limca Book of Records.

Fig. 4 Ludhiana Railway station (Vertical garden) (Source: ibid)

Scale	City and Country	Year	Issues	Vertical Garden Approach	Outcomes
City level	**Ludhiana, India**	**2018**	Excess usage of plastics Air pollution- Ludhiana was ranked 40th among the world's most polluted city	It not only reuses plastic but also helps in substantial reduction of surrounding pollution and this innovative project emerged as a response to the growing concerns over air pollution and plastic waste. Eliminates ultra- fine dust pollutants The vertical garden at the Ludhiana railway station lowered the local Air Quality Index (AQI) to 78, compared to the city's overall AQI of 275, demonstrating their potential in combating pollution in Tier 2 cities across India (Dawar, 2023). There is only one opening from where water can be poured which percolates down to every single bottle. As soon as all the bottles get filled the water automatically stops flowing thus avoiding any spillage or wastage. Greem walls absorbes the heat and reduce 2-3 reduced temperature The station director also highlighted the cleanliness of the train station, stating that since the vertical gardens were introduced, there have been less instances of people spitting gutkas and paan masalas on the walls.	**Environmental** **Technical** **Social (behavioural change)**

Challenges under current circumstances at the National Level

One of the main challenges is integrating vertical gardens into existing public spaces structures. This requires careful planning and design to ensure the gardens can be safely supported and maintained. Some key points to consider:

- Assessing the load-bearing capacity of station walls and roofs
- Designing suitable mounting systems for planters or trellises
- Ensuring proper drainage and waterproofing to protect infrastructure

Vertical gardens in Ludhiana railway stations face unique maintenance challenges compared to traditional outdoor gardens:

- Need for regular watering and fertilizing
- Pruning and pest control to keep plants healthy

- Potential for vandalism or damage from heavy foot traffic
- Ensuring accessibility for maintenance staff

There are economic considerations to weigh and analyze:

- Initial investment costs for installation and materials
- Ongoing maintenance expenses
- Water usage for irrigation (especially in water-scarce regions)
- Potential energy consumption for lighting or climate control

While there are challenges, many cities are successfully integrating vertical gardens into residential and public spaces to enhance sustainability and public experiences. Careful planning and collaboration between transportation authorities, architects, and landscape professionals is key to overcoming these hurdles.

As discussed in the evolution of the Vertical Garden conceived and realized by the botanist Patrick Blanc (he was awarded an Honorary Fellow of the Royal Institute of British Architects. He is a French botanist and a modern innovator of the green wall, or the vertical garden), The vertical garden depends on plants as they need light, air, suitable temperature, water and required minerals. Contrary to general beliefs, plants can vegetate without soil. This led French botanist Patrick Blanc to create and patent his first green walls called Vertical Garden.

When there are no more spaces available for plants, a vertical garden is the ideal way to add lovely plants to any area. The answer depends on the plants' capacity to grow roots in a thin, vertical layer of acrylic. Plants can be grown on any vertical structure with this capability. In essence, the construction is incredibly lightweight and may be permanently installed on any building's wall.

A drilled hose that runs along the top of the Vertical Garden, etc., can be used to mechanically water it. Grey water recycling might be feasible. Any size vertical garden is possible. There are already more than a thousand vertical gardens worldwide. Paris is home to the biggest Vertical Garden. It is 30 meters high and has a 300 square meter area. Vertical gardens can be installed in any city on the globe because they can be used in any type of environment, including indoor or outdoor ones with light, wind, temperature, and humidity.

Given the Indian setting, developers can be encouraged to offer Vertical Gardens and associated services by offering financial incentives, particularly in the Delhi NCR area. The reward might take the form of a 5% increase in the floor area ratio (F.A.R.) for their advanced construction. It could be modelled after the Leeds/EGBC incentive scheme for meeting sustainability requirements for platinum certification. Public gardens, parks, or jogging tracks can add small, free-standing vertical gardens that improve joggers' visual perception while they're exercising. Kids can also see these gardens in parks because they think they're unique or resemble fictional characters, which inspires them to have something similar at home. In order to encourage the public to create a visual library of vertical gardens in small-scale parks, metro pillars, school buildings, amusement parks, movie theatre's etc.

Will boost the effort as Children picks up hobby fast with good motivation and inspiration. • Also such parks will employ full time Gardner & farmers etc.

Education- College Level. Introduction to vertical garden, like bottle plants etc, which will create interest in students .Also incentive for College or funding to have such Vertical Gardens in college premises.Indian ethos, our ancestor /grandparents used to have small urban farms in their back yards eg. Tulsi, pepper, grape tomato etc. they already have close nature environment & they value plants & trees

Policy Recommendations for Regulatory Frameworks

Following policy recommendations aim to create a supportive regulatory framework that facilitates the adoption and long-term sustainability of vertical gardens in railway stations across cities. Governments should introduce tax breaks or subsidies for railway stations implementing vertical gardens. These financial incentives can offset initial setup costs and encourage widespread adoption. This approach has proven successful in urban areas where green infrastructure is promoted. Develop clear guidelines for the installation and maintenance of vertical gardens, including specifications on the types of plants, structural

integrity, and water usage. These guidelines should ensure that vertical gardens are safe, sustainable, and suitable for the local climate and infrastructure. Encourage collaborations between government bodies, private companies, Universities and environmental NGOs to fund and maintain vertical gardens. PPP models can leverage the strengths of each sector, combining public oversight with private innovation and efficiency.

Initiate pilot projects in selected Tier city stations to refine best practices before broader implementation. fund research to explore innovative materials and plant species that can enhance the effectiveness of vertical gardens in various climatic conditions.

Integrate vertical gardens into broader urban planning initiatives as part of URDFI Guidelines and regulations

CONCLUSIONS

In urban areas where population density and pollution levels are high, vertical gardens play a critical role in enhancing green spaces and improving air quality. They offer a viable solution for mitigating environmental challenges, making them an essential component of urban planning strategies aimed at controlling pollution and improving living conditions. The overall success of vertical gardens in urban settings depends on a well-thought-out approach that maximizes their environmental benefits while addressing the practical challenges of their implementation and upkeep.

In conclusion, the successful implementation of vertical gardens faces several challenges, particularly in terms of construction, plant selection, and maintenance. For vertical gardens to be effective, it is essential that the spaces used are sustainable and well-suited to the local environment. Careful consideration must be given to the selection of plants, focusing on species that are adaptable to vertical growth and compatible with the local climate, especially in the humid and warming conditions prevalent in many parts of India. Proper irrigation methods and maintenance practices are crucial to the longevity and effectiveness of these gardens.

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The ethical approval is NOT REQUIRED for this research.

SHARMILA JAGADISAN

CONFLICT-OF-INTEREST STATEMENT

The authors have no conflicts of interest to declare. The co-author have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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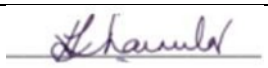
Informed Consent

This research is written by Ankit Kumar and Sharmila Jagadisan , School of Architecture, Vellore Institute of Technology, Vellore

This study is done as part of the PhD work, and it is an academic research.

1	**'Clinical trial number:**	**Not applicable for this manuscript**	 **15.06.2025**
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