PLANT SCIENCE TODAY
Vol 12(2): 1-12
https://doi.org/10.14719/pst.8565

eISSN 2348-1900

REVIEW ARTICLE

Biophilic gardens for enhancing urban ecosystems and reconnecting people with nature

P Infant Nijole[1], K Kumanan[2*], C Subesh Ranjith Kumar[1*], S Umesh Kanna[3], K P Ragunath[4] & M Mohamed Asik[1]

[1]Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[2]Coconut Research Station, Veppankulam 614 906, Tamil Nadu, India

[3]Department of Agroforestry, Forest College and Research Institute, Mettupalayam 641 301, Tamil Nadu, India

[4]Centre for Water and Geospatial Studies, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - kumanan@tnau.ac.in, subesh@tnau.ac.in

Received: 28 March 2025; Accepted: 30 April 2025; Available online: Version 1.0: 17 May 2025; Version 2.0 : 24 May 2025

Cite this article: Infant Nijole P, Kumanan K, Subesh CRK, Umesh SK, Ragunath KP, Mohamed MA. Biophilic gardens for enhancing urban ecosystems and reconnecting people with nature. Plant Science Today. 2025; 12(2): 1-12. https://doi.org/10.14719/pst.8565

Abstract

The rapid growth of cities and the shift toward highly urbanized lifestyles have distanced humanity from its innate connection with nature. This disconnection has taken a toll on mental health, physical well-being and overall quality of life. Biophilic gardens emerge as a revolutionary approach to reconnect people with nature by weaving natural elements into the fabric of urban environments. Rooted in the biophilia hypothesis, it emphasizes the profound psychological and physiological benefits of integrating features like greenery, natural light and organic forms into built spaces. This review explores the evolution of biophilic gardens, distinguishing itfrom sustainable design while underscoring its unique focus on nurturing human-nature relationships. Practical strategies, from incorporating green walls and water features in buildings to creating biodiverse urban landscapes, are discussed alongside compelling real-world examples. Projects like Singapore's Khoo Teck Puat Hospital and Milan's Bosco Verticale demonstrate how Biophilic gardens can transform spaces into vibrant, health-promoting ecosystems, enhancing well-being, productivity and environmental resilience. While the benefits are undeniable, challenges such as costs, maintenance and scalability remain hurdles. Looking ahead, the integration of smart technologies, biomimicry and regenerative practices could unlock new possibilities. Biophilic gardens offers a hopeful vision for the future, where cities become havens of harmony between humans and nature, fostering healthier, more sustainable communities.

Keywords: biophilic gardens; health; human-nature connection; nature integration; sustainable architecture; urban resilience; well-being

Introduction

The rapid urbanization and technological advancements of the modern era have significantly disrupted humanity's intrinsic connection to nature, a concept referred to as "biophilia," which denotes the love of life or living systems (1). As urban areas expand and lifestyles become more sedentary, the disconnection from natural environments has adversely affected mental health and overall well-being (2). Research highlights that, individuals in urban settings experience increased levels of stress, anxiety and depression, largely due to the limited access to nature (3). Biophilic gardens, rooted in the biophilia hypothesis (4), has emerged as a transformative architectural approach aimed at re-establishing this connection by integrating natural elements into built environments. By incorporating features such as green walls, water elements and natural materials, Biophilic gardens enhances both aesthetic appeal and psychological well-being while promoting sustainability (5, 6). The practice fosters a stronger emotional bond between humans and their surroundings and has been applied in diverse settings, from hospitals to universities, contributing to improved health, resilience and sustainability (7, 8). Furthermore, the COVID-19 pandemic has underscored the importance of nature-connected spaces in enhancing human health and well-being, prompting a re-evaluation of urban spaces and their role in promoting mental and physical health (9, 10). Despite the established benefits, challenges remain in applying biophilic principles to different design and policy interventions across various scales. Moving forward, a more nuanced understanding of the interplay between Biophilic gardens, health outcomes and regenerative goals is required to maximize its potential for enhancing human and environmental well-being (11).

Understanding biophilia and biophilic gardens

The concept of biophilia

The term "biophilia" was first coined by social psychologist Erich Fromm in 1973, describing it as "the passionate love of life and all that is alive" (12). However, it was biologist Edward O. Wilson who popularized the concept in his 1984 book "Biophilia," where he defined it as "the innate

tendency to focus on life and lifelike processes" (13). Wilson argued that this affinity for nature is deeply rooted in our evolutionary history and is essential for our physical, emotional and intellectual growth. The biophilia hypothesis suggests that humans have an innate biological need to connect with nature and other forms of life. This connection is not merely a preference but a fundamental aspect of our well-being. Throughout human evolution, our ancestors lived near nature, developing intricate relationships with their natural surroundings. These relationships were crucial for survival, influencing our cognitive, emotional and physical development.

The evolution of biophilic gardens

Biophilic gardens emerged as a practical application of the biophilia hypothesis in architecture and urban planning. It aims to satisfy our innate need for nature by incorporating natural elements, patterns and processes into the built environment. The concept gained significant traction in the late 20th and early 21st centuries as researchers began to document the positive effects of nature on human health and well-being. The framework for Biophilic gardens identifies three primary categories: the direct experience of nature, the indirect experience of nature and the experience of space and place. These categories form the foundation for implementing biophilic principles in architectural and urban design. However, it is important to distinguish Biophilic gardens from green or sustainable design (Table 1), although the two concepts often overlap.

The growing importance of biophilic gardens

In recent years, Biophilic gardens has gained increased attention and importance for several reasons (Fig. 1). As we delve deeper into the principles and applications of Biophilic gardens in the following sections, it becomes clear that this approach is not just a design trend, but also a fundamental shift in how we conceive and create our built environments. By reconnecting humanity with nature, Biophilic gardens hold the promise of creating more liveable, sustainable and nurturing spaces for current and future generations.

The importance of biophilic gardens in modern architecture

The integration of Biophilic garden principles into modern architecture has become increasingly crucial (14) as we navigate the challenges of the 21st century. This section explores why Biophilic gardens is not just a passing trend but also a necessary evolution in how we approach the built environment.

Addressing the nature deficit

In his influential book "Last Child in the Woods," Richard Louv coined the term "nature-deficit disorder" to describe the human costs of alienation from nature (15). While not a medical diagnosis, this concept highlights the myriads of problems (Fig. 2) associated with our increasing disconnection from the natural world. Biophilic gardens directly addresses these concerns by bringing elements of nature into our daily lives, even in the most urban of settings. By incorporating natural light, vegetation, water

Fig. 1. Need for introducing biophilic gardens (66, 68).

Table 1. Biophilic gardens vs. Green design (7)

Biophilic gardens	Green design
Emphasizes the human-nature connection and its benefits for human well-being.	Primarily focuses on reducing the environmental impact of buildings and urban spaces.
Seeks to incorporate natural elements and experiences into the built environment to enhance human well-being.	Involves strategies such as energy efficiency, water conservation and the use of sustainable materials.
Aims to improve human mental and physical health by creating nature-centric spaces.	Aims to achieve environmental sustainability by minimizing resource consumption and waste.
Examples include the use of natural lighting, ventilation, green spaces and water features to improve human experience.	Examples include renewable energy, recycled materials and energy-saving technologies.
Often complements green design in aspects like natural lighting and ventilation for energy efficiency.	Does not necessarily address the human need for connection with nature.

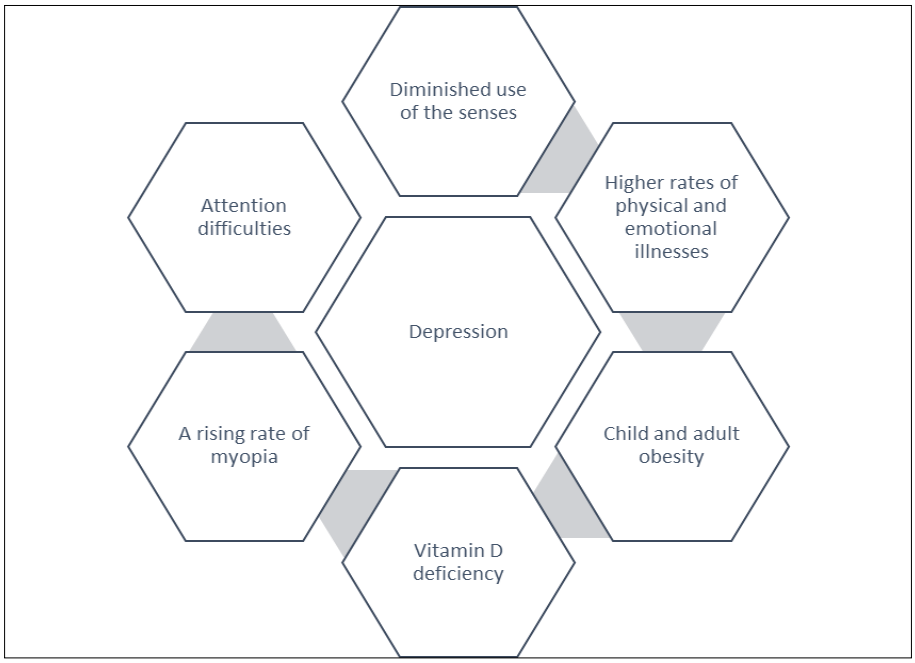

Fig. 2. Nature deficit issues.

features and natural materials into buildings and urban spaces, architects and designers can help mitigate the effects of nature deficit disorder.

Enhancing human health and well-being

A growing body of research demonstrates the positive impacts of Biophilic gardens on human health and well-being (Fig. 3). By incorporating these health-promoting elements into our built environments, Biophilic gardens can play a crucial role in public health strategies.

Boosting productivity and satisfaction in the workplace

Biophilic gardens in work environments offer significant benefits for employee well-being and organizational performance. Employees working in spaces with natural elements report a 15 % higher level of well-being, are 6 % more productive and demonstrate 15 % greater creativity, as highlighted by the World Green Building Council (16). Incorporating natural elements into office designs has also been linked to a 15 % reduction in absenteeism (17). Access to natural light and views of nature enhances job satisfaction and fosters stronger organizational commitment among employees (18). Furthermore, office environments featuring biophilic elements contribute to stress reduction, with a 15 % increase in self-reported well-being, reflecting lower levels of work-related stress (19). These findings emphasize the economic and human value of Biophilic gardens, making it an appealing strategy for businesses aiming to improve both employee satisfaction and productivity.

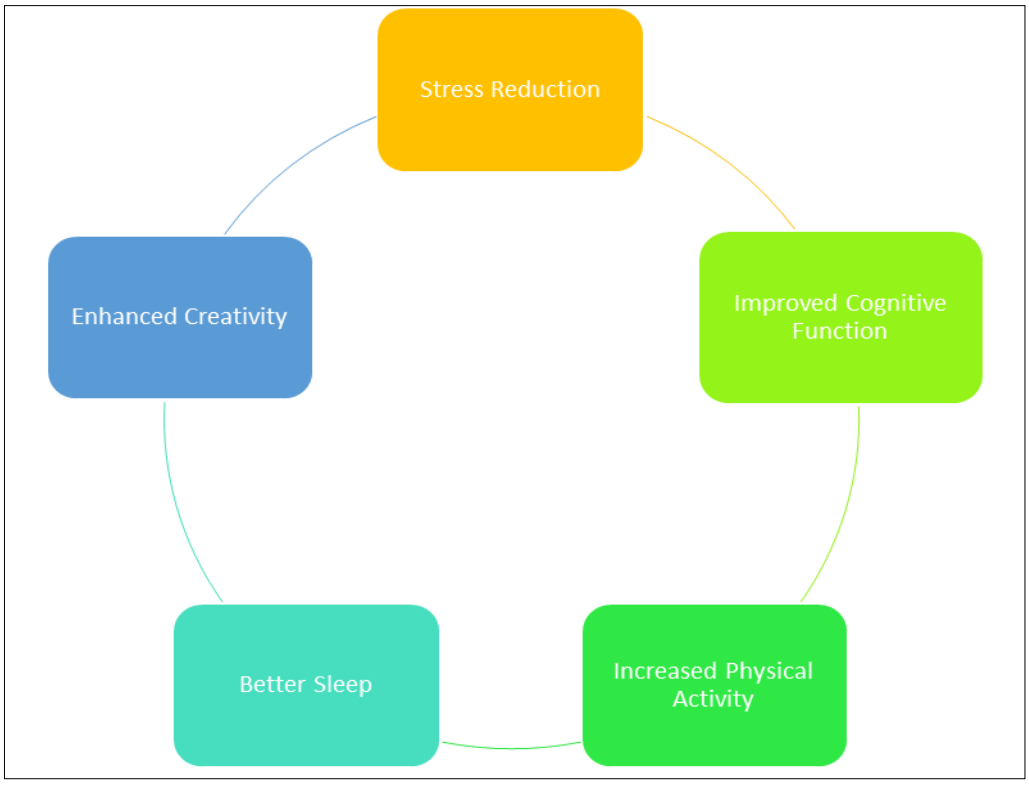

Fig. 3. Positive impacts of Biophilic gardens on human health (69-71).

Contributing to sustainable urban development

Biophilic gardens addresses critical environmental challenges, fostering more resilient and sustainable urban environments. Energy efficiency is achieved through natural lighting and ventilation strategies, reducing dependence on artificial lighting and Ventillation systems, which leads to significant energy savings. Green roofs, vertical gardens and urban parks play a vital role in mitigating the urban heat island effect, thereby lowering cooling costs and improving air quality (20). Biophilic elements such as bioswales and rain gardens enhance stormwater management by reducing runoff and easing the burden on urban infrastructure. Additionally, the integration of diverse plant species in urban landscapes creates habitats for local flora and fauna, promoting urban biodiversity. Urban vegetation further contributes to climate change mitigation by acting as a carbon sink, sequestering atmospheric carbon dioxide .The study estimated that urban trees in the United States remove 711000 metric tons of air pollution annually (21). Collectively, these strategies demonstrate how Biophilic gardens supports environmental sustainability and urban resilience.

Fostering environmental stewardship

Perhaps one of the most profound impacts of Biophilic gardens is its potential to foster a greater sense of environmental stewardship. By bringing people into daily contact with nature, even in urban settings, Biophilic gardens can help nurture an emotional connection to the natural world. This connection is crucial for developing environmental awareness and encouraging pro-environmental behaviours (22). As people become more attuned to the natural processes around them, they are more likely to value and protect the environment. This shift in perspective is essential as we face global environmental challenges and seek to create more sustainable societies. In conclusion, the importance of Biophilic gardens in modern architecture cannot be overstated. It offers a holistic approach to addressing many of the challenges we face in our increasingly urbanized world – from public health concerns to environmental sustainability. By reconnecting people with nature in the built environment, Biophilic gardens has the potential to transform our cities, workplaces and homes into spaces that nurture both human well-being and environmental stewardship.

Implementing biophilic gardens: strategies and techniques

Implementing Biophilic gardens involves a range of strategies and techniques that can be applied at various scales, from individual buildings to entire urban landscapes. This section explores practical approaches to incorporating biophilic elements into the built environment.

Horticultural strategies

Biophilic horticultural elements in architecture enhance both aesthetic appeal and functional benefits. Green walls and roofs serve as visually appealing features while offering insulation, improving air quality and creating habitats for urban wildlife (23). Skylights and atriums allow natural light to penetrate deep into buildings, fostering connections with the outdoors and supporting occupants' circadian rhythms (24). Biomorphic forms and patterns, inspired by shapes and designs found in nature, subtly connect indoor spaces to the natural world (25). Using natural materials like wood and stone adds tactile and visual links to nature and can contribute to better indoor air quality (26). Water features, such as fountains or ponds, provide multi-sensory experiences, enhance acoustic comfort and introduce calming elements to spaces (27). Maximizing views of nature, even within urban environments, offers significant psychological benefits, including reduced stress and increased well-being (28). These elements create holistic environments that promote harmony between people and their surroundings.

Landscape design strategies

Sustainable and restorative landscape design integrates several key strategies to benefit both people and the environment. Utilizing native plant species enhances biodiversity, supports local ecosystems and minimizes maintenance needs due to their natural adaptation to the area (29). Designing landscapes to attract and support local wildlife, such as birds, insects and small mammals, enrich ecosystems and fosters ecological balance (30). Sensory gardens engage multiple senses by incorporating fragrant plants, textured surfaces and edible landscapes, creating inclusive and stimulating environments for all visitors (31). Water management practices like rain gardens and bioswales are essential for controlling stormwater runoff, reducing erosion and filtering pollutants, contributing to sustainable water use (32). Natural play areas that use elements such as logs, sand and water instead of traditional playground equipment encourage imaginative and unstructured play while fostering a deeper connection to nature (33). Additionally, therapeutic landscapes, particularly in healthcare or community settings, provide restorative outdoor spaces and modified indoor spaces that promote mental and physical well-being (34). Together, these approaches support ecological sustainability and human health.

Urban planning strategies

Urban sustainability and ecological resilience can be enhanced through innovative design strategies. Green corridors, which create interconnected networks of green spaces, support biodiversity while providing recreational opportunities in urban areas (35). Expanding urban forests increases tree canopy cover, improving air quality, mitigating the urban heat island effect and offering habitats for wildlife (36). Biodiverse green spaces are essential for designing parks and public areas that support diverse plant and animal life, enriching urban ecosystems (37). Blue-green infrastructure integrates water management with green spaces, creating multifunctional landscapes that manage stormwater while enhancing urban aesthetics (38). Ecological restoration aims to rehabilitate degraded urban ecosystems, offering both ecological and social benefits, including enhanced biodiversity and improved public well-being. A notable example is Singapore's transformation into a "City in a Garden," which has not only revitalized its urban environment but also contributed to its consistently high

rankings in global liveability indices. This integration of nature within the cityscape has strengthened Singapore's appeal as a destination for both tourists and skilled professionals, demonstrating the potential of ecological restoration to create vibrant, sustainable urban spaces (39). Additionally, biophilic streets incorporate natural elements into urban roadways, fostering walkability and enhancing the liveability of city environments (40). These approaches collectively contribute to healthier, more sustainable urban landscapes.

Technological integration

Innovative Biophilic garden strategies are transforming interior spaces to enhance human well-being and environmental sustainability. Dynamic lighting systems, which mimic natural light patterns, are being utilized to align indoor lighting with human circadian rhythms, improving health and productivity (41). Living walls, designed with advanced hydroponic systems, bring lush vertical gardens into interior spaces, enhancing air quality and aesthetics (42). Biomimetic building systems draw inspiration from nature, integrating processes like natural ventilation, temperature regulation and water management to enhance energy efficiency in structures. A prominent example is the Eastgate Centre in Harare, Zimbabwe, which utilizes a ventilation system modelled after termite mounds. This design minimizes energy consumption by regulating indoor temperatures without relying on conventional air conditioning, showcasing the potential of biomimicry to create sustainable and cost-effective architectural solutions (43). In settings where direct exposure to nature is impractical, virtual nature through virtual reality or large-scale displays offers immersive natural experiences, reducing stress and improving focus (44). Smart sensors further optimize biophilic elements by adjusting natural ventilation, lighting and other environmental factors in real-time (45). Additionally, bio reactive facades integrate living organisms like algae into building designs, generating renewable energy while contributing to temperature regulation and carbon capture (46). These cutting-edge approaches bridge technology and nature, fostering healthier and more sustainable built environments. Implementing these strategies requires a holistic approach that considers the specific context of each project, including climate, culture and existing urban fabric. Successful Biophilic gardens places significant emphasis on the expertise, knowledge and skills of horticulturists, whose selection, arrangement and maintenance of plants play a crucial role in creating environments that promote well-being and ecological balance.

Case studies: Successful biophilic garden projects

To truly appreciate the impact and potential of biophilic gardens, it is essential to examine real-world examples where these principles have been successfully implemented. This section explores a diverse range of projects that showcase innovative approaches to integrating nature into the built environment.

The Khoo Teck Puat Hospital, Singapore

The Khoo Teck Puat Hospital in Singapore stands as a prime example of Biophilic gardens in healthcare settings. Opened in 2010, the hospital was designed with the vision of creating a "hospital in a garden and a garden in a hospital" (47). The design team, incorporated extensive greenery throughout the facility, including healing gardens, green roofs and cascading planted terraces. One of the most striking features of the hospital is its central courtyard, which houses a large pond teeming with fish and aquatic plants. This water feature not only provides a calming focal point but also helps to cool the surrounding areas naturally. The building's façade is adorned with vertical gardens, which not only enhance the aesthetic appeal but also improve air quality and reduce the urban heat island effect. The hospital's design goes beyond mere visual appeal (Fig. 4). It incorporates natural ventilation strategies, maximizes daylight and provides patients with views of nature from their rooms. These design elements have contributed to improved patient outcomes, with studies showing faster recovery times and reduced need for pain medication among patients (47).

Fig. 4. Biophilic gardening in Khoo Teck Puat Hospital, Singapore (72).

The Bullitt Center, Seattle, USA

Often described as the "greenest commercial building in the world," the Bullitt Center in Seattle is a testament to the integration of Biophilic gardens with cutting-edge sustainable technologies. The building aims to function like a living organism, adapting to its environment and operating at maximum efficiency (48). The Bullitt Center maximizes natural daylight through its floor-to-ceiling windows and a central atrium. The building's smart windows automatically adjust tint to optimize light and heat gain. A prominent feature is the dramatic staircase, designed to be inviting and flooded with natural light, encouraging occupants to use stairs instead of elevators. The building's relationship with water is particularly noteworthy. It captures rainwater for all its water needs and treats all wastewater on-site. The surrounding landscape features native plants that require no irrigation beyond natural rainfall, demonstrating how urban buildings can harmonize with local ecosystems (Fig. 5). Perhaps most importantly, the Bullitt Center has shown that biophilic and sustainable design can be economically viable. The building has outperformed expectations in terms of energy efficiency and has proven attractive to tenants, maintaining high occupancy rates (48).

Bosco Verticale, Milan, Italy

Bosco Verticale, or "Vertical Forest," is a pair of residential towers in Milan that takes the concept of urban greening to new heights. These towers are home to over 900 trees and 20000 plants, distributed across balconies and facades (49). This project demonstrates how Biophilic gardens can be integrated into high-density urban environments. The vegetation provides numerous benefits: it absorbs Carbon dioxide and dust particles, produces oxygen, moderate temperatures in the building and creates a changing natural backdrop for residents as seasons progress. The design of Bosco Verticale goes beyond aesthetics. The plant species were carefully selected to thrive in their specific locations on the towers, considering factors like height, orientation and microclimate (Fig. 6). The irrigation system uses greywater from the buildings, demonstrating an integrated approach to resource management. Bosco Verticale has become a model for biophilic high-rise design, inspiring similar projects around the world. It shows how urban densification can be reconciled with the need for green spaces, creating a new typology of urban nature (49).

Biophilic gardens in India

In India, biophilic architectural concepts are gradually gaining importance in urban design and residential planning. An extensive study on the environmental impact of biophilic architecture on human health was conducted in Greater Noida, focusing on landmark residential complexes such as ATS Greens Paradiso, Jaypee Greens and Purvanchal Heights. Their research demonstrated the significance of integrating biophilic elements such as vegetation, water bodies, passive ventilation, daylighting and natural materials in improving the well-being, comfort and social interactions of the residents. Vegetation was found to have the most prominent effect on inhabitants' health and stress reduction (50).

Additionally, projects like The Forest Office in Gurugram by Studio Lotus, Infosys Mysuru Campus, Sunder Nursery in New Delhi and One Avighna Park in Mumbai have adopted biophilic principles through the inclusion of green roofs, courtyards, vertical gardens and natural material usage. India's smart city initiatives, such as Amaravati and GIFT City, are also promoting biophilic infrastructure development in urban areas through green corridors, rooftop gardens and eco-sensitive design strategies. These examples collectively highlight India's growing emphasis on integrating nature with built environments for enhanced urban resilience and human wellbeing.

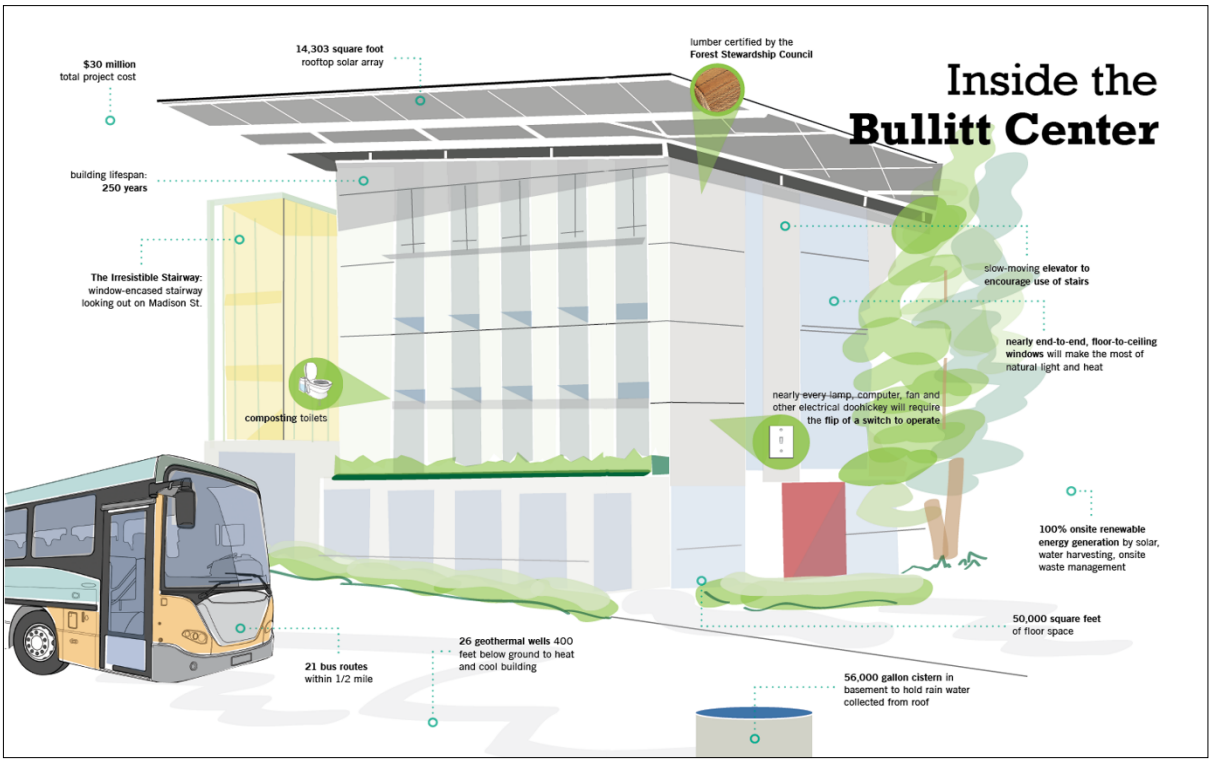

Fig. 5. Biophilic architecture of Bullitt Center in Seattle.

Fig. 6. Biophilic forest building of Bosco Verticale, Milan, Italy.

Initiatives of Tamil Nadu Agricultural University

Tamil Nadu Agricultural University (TNAU) has pioneered research initiatives integrating Biophilic gardens with horticulture to enhance urban sustainability and resilience. The university has conducted extensive studies on felt-based living walls, assessing their role in mitigating urban heat, improving air quality and enhancing aesthetics. Research also focuses on selecting plant species that optimize heat reduction and air pollution control in biophilic vertical gardens. Additionally, studies on greywater utilization in living walls explore sustainable irrigation strategies, promoting resource-efficient urban greening. These efforts underscore TNAU's commitment to advancing climate-responsive, biophilic horticultural practices in built environments.

Benefits of biophilic gardens

The implementation of Biophilic gardens principles offers a wide array of benefits that extend beyond mere aesthetic enhancement. These advantages span across health, productivity, environmental sustainability and economic domains, making a compelling case for the widespread adoption of Biophilic gardens in our built environments.

Health and well-being

One of the most significant benefits of Biophilic gardens is their positive impact on human health and well-being. Numerous studies have demonstrated that exposure to natural elements can lead to improved physical and mental health outcomes. For instance, hospital patients with views of nature from their windows recovered faster and required less pain medication compared to those facing brick walls. This groundbreaking study paved the way for further research into the healing effects of nature in healthcare settings. Biophilic gardens garden elements in the workspace have been associated with reduced stress levels. Workers with greater exposure to natural elements reported lower perceived stress and higher overall well-being (51). This stress-reduction effect is thought to be linked to nature's ability to promote parasympathetic nervous system activity, which helps the body relax and recover from stress (52). Moreover, Biophilic gardens can contribute to improved air quality. Indoor plants, a common feature in biophilic spaces, have been shown to reduce concentrations of volatile organic compounds and other indoor air pollutants (53). This can lead to reduced incidence of sick building syndrome and other respiratory issues. The mental health benefits of Biophilic gardens are equally impressive. Exposure to nature has been linked to reduced symptoms of depression and anxiety, improved mood and enhanced cognitive function (54).

Productivity and creativity

In addition to health benefits, Biophilic gardens have been shown to enhance productivity and creativity in various settings. This makes it particularly valuable in the workplace and educational environments. A landmark study found that office workers with views of nature from their desks performed 10 % to 25 % better on mental function and memory recalls test than those without such views (55). Similarly, a study conducted in call centers showed that workers with views of vegetation handled calls 6-7 % faster than those with no views of nature (55). Biophilic gardens elements can also boost creativity. A study has found that participants showed a 50 % improvement in creative problem-solving after immersion in nature (56). While full immersion may not be possible in most built environments, even small doses of nature

through Biophilic gardens can stimulate creative thinking. In educational settings, Biophilic gardens has been associated with improved student performance. A study of 751 students in the US found that students in classrooms with views of green landscapes performed 20 % to 26 % faster on tests than those in classrooms without green views (57).

Environmental sustainability

Biophilic gardens often go hand in hand with sustainable design practices, offering significant environmental benefits. When implemented on a large scale, these benefits can contribute to addressing major environmental challenges. One of the most direct environmental benefits is improved air quality. Urban forests and green spaces, key elements of biophilic urban design, act as natural air filters, removing pollutants and producing oxygen. Biophilic gardens can also play a role in mitigating the urban heat island effect. Green roofs and walls increased urban tree cover and the integration of water features can help lower urban temperatures. A study in Manchester and the United Kingdom found that increasing urban green space by 10% could reduce surface temperatures by up to 2.5 °C (58). Moreover, Biophilic gardens strategies like green infrastructure can contribute to stormwater management, reducing the burden on urban drainage systems and decreasing the risk of flooding. Philadelphia's Green City, Clean Waters program, which emphasizes green infrastructure, is expected to reduce combined sewer overflows by 85 % (59). Biodiversity conservation is another important environmental benefit of Biophilic gardens. By incorporating diverse native plant species and creating habitats for local wildlife, biophilic urban spaces can support ecosystem services and help maintain biodiversity in urban areas (60).

Economic benefits

While the implementation of Biophilic gardens may require initial investments, it often results in significant economic benefits over time. These benefits can be observed at both the individual building level and the broader urban scale. At the building level, Biophilic gardens can lead to energy savings. Features like green roofs and walls provide natural insulation, reducing heating and cooling costs. A study by the National Research Council of Canada found that a green roof can reduce summer energy demand for air conditioning by over 75 % (61). In retail environments, Biophilic gardens has been associated with increased customer spending. Wolf (62) found that customers were willing to pay 20 % more for goods in shopping areas with trees compared to those without. The health benefits of Biophilic gardens translate into economic benefits through reduced healthcare costs and absenteeism.

For example, a study of the Khoo Teck Puat Hospital in Singapore, mentioned earlier in our case studies, found that its Biophilic gardens contributed to reduced patient stay times and lower re-admission rates, resulting in significant cost savings (63). On a broader scale, biophilic urban design can increase property values and attract investment. Studies have shown that proximity to parks and green spaces can increase property values by 8 % to 20 % (64). This not only benefits property owners but also increases municipal tax revenues. Furthermore, cities that prioritize Biophilic gardens often see benefits in terms of tourism and talent attraction. The benefits of Biophilic gardens are multifaceted and far-reaching. From improving individual health and well-being to enhancing productivity, supporting environmental sustainability and driving economic growth, Biophilic gardens offers a powerful set of strategies for creating built environments that are not only more pleasant to inhabit but also more sustainable and economically viable. As we face the challenges of rapid urbanization and environmental degradation, the adoption of Biophilic gardens principles presents an opportunity to create cities and buildings that nurture both people and nature.

Health and business relevance: A horticulture-based approach

From a health perspective, incorporating horticultural elements into indoor and outdoor spaces enhances air quality, reduces stress and promotes mental well-being. Plants such as Peace Lily, Snake plant and Aloe vera are known for their air-purifying properties. The presence of greenery in workplaces has been shown to reduce fatigue, improve concentration and boost cognitive performance, resulting in higher productivity and reduced absenteeism.

The business relevance of Biophilic gardens is evident in its impact on employee satisfaction and operational efficiency. Indoor gardens and green break-out zones can foster creativity and collaboration, while natural lighting combined with strategically placed plants can create inviting and productive work environments. In retail spaces, incorporating natural elements has been found to enhance customer experiences, leading to increased dwell time and higher sales. For hotels and resorts, landscaped gardens with native flowering plants and water features can attract guests seeking tranquil and aesthetically pleasing environments.

Challenges and considerations in biophilic gardens

One of the primary challenges in implementing Biophilic gardens is the perception of increased costs. Initial investments in features such as green roofs, living walls, or sophisticated natural lighting systems can be substantial. For instance, the construction costs of a green roof can be 50 % to 100 % higher than those of a conventional roof (65). However, it is essential to consider these costs in the context of long-term benefits and return on investment. The challenge lies in convincing stakeholders to look beyond initial costs and consider the long-term economic benefits, including energy savings, increased property values and improved occupant health and productivity. Integrating views to nature into an office space can save a part in office costs, while daylighting offices can result in a 6 % boost in worker productivity (66). Communicating these long-term benefits effectively is crucial for overcoming cost-related hesitations.

Customizing biophilic gardens for Indian tropical climates

In the context of Indian tropical climates, biophilic gardens must be tailored to suit environmental conditions such as high temperatures, humidity and seasonal variations. Incorporating native and climate-resilient plant species is

essential to ensure sustainability and reduce maintenance costs. For example, tropical trees like *Ficus benjamina*, Areca palm and Bougainvillea thrive in warm climates and require minimal care. Green roofs planted with heat-tolerant species like *Portulaca sp*, sedums and drought-resistant grasses can reduce indoor temperatures, enhancing thermal comfort and lowering cooling costs.

Living walls can be customized using species such as *Epipremnum aureum, Chlorophytum comosum* and ferns, which not only thrive in humid conditions but also improve air quality. Vertical gardens with flowering plants like Ixora and Hibiscus can add aesthetic appeal while supporting pollinators, contributing to urban biodiversity. Designing courtyards with shaded seating areas surrounded by flowering shrubs like Jasmine and Gardenia creates visually pleasing and thermally comfortable outdoor spaces.

Future trends in biophilic gardens

As our understanding of the human-nature connection deepens and technology continues to advance, the field of Biophilic gardens is poised for exciting developments. Future trends in Biophilic gardens are likely to be shaped by emerging technologies, changing urban landscapes and evolving environmental challenges. Here, we explore some of the key trends that may define the future of Biophilic gardens.

Biomimicry and regenerative design

The future of Biophilic gardens is likely to see closer integration with the principles of biomimicry and regenerative design. Biomimicry involves emulating nature's time-tested patterns and strategies to solve human design challenges. In the context of Biophilic gardens, this could lead to buildings that incorporate natural elements and function more like natural systems. For instance, we might see buildings that regulate temperature like termite mounds, capture and filter water like bromeliads, or generate energy like leaves performing photosynthesis. Regenerative design takes this concept further, aiming to create buildings and cities that enhance the health of local ecosystems rather than simply reducing harm. This could involve buildings that actively clean air and water, sequester carbon and provide habitats for diverse species.

Customized and adaptive biophilic gardens

Advances in data analytics and personalization technologies are likely to lead to more customized and adaptive Biophilic gardens. Future buildings might be able to adjust their biophilic elements based on the preferences and physiological responses of individual occupants. For example, workspaces might automatically adjust lighting conditions, introduce natural sounds, or change the visibility of green elements based on an employee's stress levels or task requirements. In healthcare settings, patient rooms might adapt their biophilic features to support specific healing processes or individual patient needs. This trend towards personalization in Biophilic gardens will require careful consideration of privacy concerns and the ethical use of personal data.

Biophilic gardens in space habitats

Looking further into the future, as humans contemplate long-term space habitation, Biophilic gardens principles are likely to play a crucial role in creating liveable environments beyond Earth. NASA and other space agencies are already researching how to incorporate plants and natural elements into space habitats to support astronaut physical and mental health on long-duration missions (67). These extreme environments will present unique challenges for Biophilic gardens, potentially driving innovations that could also benefit Earth-based applications. The future of Biophilic gardens holds exciting possibilities for creating built environments that are not only more natural but also smarter, more personalized and more ecologically regenerativeAs the world faces challenges such as climate change, biodiversity loss and urbanization, Biophilic gardens presents an effective solution for developing resilient, healthy and nurturing environments that benefit both people and nature. The key to realizing this potential lies in continued research, interdisciplinary collaboration and a commitment to integrating nature into every aspect of our built environment.

Biophilic gardens in academic spaces

Bringing nature back into our everyday spaces has a powerful impact on how we feel, think and connect with the world around us. A recent study on university campuses showed that when places are designed with nature in mind, adding greenery, water features, natural light and natural materials, it helps people feel calmer, happier and more focused. Green spaces and gardens on these campuses do more than just look nice; they create peaceful spots for people to relax, recharge and reconnect with nature (68). If cities embraced these ideas by creating biophilic gardens and greener public spaces, it could transform the way people experience urban life, improving well-being, supporting local wildlife and building stronger, healthier communities in the heart of our cities.

Conclusion

Biophilic gardens fosters human well-being and ecological balance by integrating natural elements like plants, light and water. Future advancements will incorporate biomimicry, regenerative principles and adaptive solutions for sustainability, especially in tropical climates. Emerging technologies, such as dynamic lighting and bio-reactive facades, will further enhance nature-inspired spaces. With applications in therapeutic horticulture, indoor landscaping and even space habitats, Biophilic gardens offers a sustainable path to healthier, more resilient environments.

Acknowledgements

The author acknowledged the support rendered by the Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore for carrying out the research work.

Authors' contributions

PIN has written the whole manuscript. KK guided in providing technical support to write the manuscript in a proper format and approved the final manuscript. CSRK guided in providing technical support to write the manuscript in a proper format and approved the final manuscript. SUK guided to write the manuscript in a proper format and approved the final manuscript. KPR guided to write the manuscript in a proper format and approved the final manuscript. MMA guided to write the manuscript in a proper format and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Barbiero G, Berto R. Biophilia as evolutionary adaptation: An onto -and phylogenetic framework for Biophilic gardens. Frontiers in Psychology. 2021;12:700709. https://doi.org/10.3389/fpsyg.2021.700709
2. Kaplan R, Kaplan S, Brown T. Environmental preference: A comparison of four domains of predictors. Environment and Behavior. 1989;21(5):509-30. https://doi.org/10.1177/0013916589215001
3. Ulrich RS. View through a window may influence recovery from surgery. Science. 1984;224(4647):420-21. https://doi.org/10.1126/science.6143402
4. Kellert SR, Wilson EO, editors. The biophilia hypothesis. Island Press; 1993.
5. Kellert SR. Nature by design: The practice of Biophilic gardens. Yale University Press; 2018.
6. Beatley T. Biophilic cities: integrating nature into urban design and planning. Island Press; 2011.
7. Browning W, Ryan C, Clancy J. 14 patterns of Biophilic gardens. New York: Terrapin Bright Green LLC; 2014.
8. Kellert S, Calabrese E. The practice of Biophilic gardens. Terrapin Bright LLC; 2015.
9. Wu JT, Leung K, Bushman M, Kishore N, Niehus R, de Salazar PM, et al. Estimating clinical severity of COVID-19 from the transmission dynamics in Wuhan, China. Nature Medicine. 2020;26(4):506-10.
10. Surico P, Galeotti A. The economics of a pandemic: the case of Covid-19. Wheeler institute for business and development, LBS. London: London business school. 2020:1-93.
11. Mazuch R. Salutogenic and Biophilic gardens as therapeutic approaches to sustainable architecture. Architectural Design. 2017;87(2):42-7. https://doi.org/10.1002/ad.2151
12. Fittipaldi SE. The Anatomy of Human Destructiveness. By Erich Fromm. New York: Holt, Rinehart and Winston, 1973. xvi+ 521 pages. $10.95. Horizons. 1975;2(1):153-. https://doi.org/10.1017/S036096690001210X
13. Wilson EO. Biophilia. Harvard university press; 1986.
14. Croeser T, Garrard GE, Visintin C, Kirk H, Ossola A, Furlong C, et al. Finding space for nature in cities: the considerable potential of redundant car parking. npj Urban Sustainability. 2022;2(1):27. https://doi.org/10.1038/s42949-022-00073-x
15. Louv R. Last child in the woods: Saving our children from nature-deficit disorder. Algonquin books; 2008.
16. World Green Building Council. Health, Wellbeing & Productivity in Offices: The next chapter for green building. World Green Building Council; 2014.
17. Elzeyadi IM. Daylighting-bias and biophilia: Quantifying the impact of daylighting on occupants health. University of Oregon-School of Architecture & Allied Arts; 2011.
18. An M, Colarelli SM, O'Brien K, Boyajian ME. Why we need more nature at work: Effects of natural elements and sunlight on employee mental health and work attitudes. PLoS One. 2016;11(5):e0155614. https://doi.org/10.1371/journal.pone.0155614
19. Global Human Spaces Report. United States: Scribd; 2015.
20. Basics UH. Reducing Urban Heat Islands: Compendium of Strategies. US EPA. https://ghhin.org/wpcontent/uploads/reducing_urban_heat_islands_ch_1.pdf (accessed on 14 January 2011). 2011 May.
21. Nowak DJ, Crane DE. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution. 2002;116(3):381-9. https://doi.org/10.1016/S0269-7491(01)00214-7
22. Zylstra MJ, Knight AT, Esler KJ, Le Grange LL. Connectedness as a core conservation concern: An interdisciplinary review of theory and a call for practice. Springer Science Reviews. 2014;2:119-43. https://doi.org/10.1007/s40362-014-0021-3
23. Perini K, Rosasco P. Cost–benefit analysis for green façades and living wall systems. Building and Environment. 2013 ;70:110-21. https://doi.org/10.1016/j.buildenv.2013.08.012
24. Gou Z, Lau SS, Qian F. Comparison of mood and task performance in naturally-lit and artificially-lit environments. Indoor and Built Environment. 2015;24(1):27-36. https://doi.org/10.1177/1420326X13507792
25. Soderlund J, Newman P. Biophilic architecture: a review of the rationale and outcomes. AIMS Environmental Science. 2015;2(4):950-69. http://doi.org/10.3934/environsci.2015.4.950
26. Rice J, Kozak RA, Meitner MJ, Cohen DH. Appearance wood products and psychological well-being. Wood and Fiber Science. 2006:644-59.
27. Alvarsson JJ, Wiens S, Nilsson ME. Stress recovery during exposure to nature sound and environmental noise. International Journal of Environmental Research and Public Health. 2010;7(3):1036-46. https://doi.org/10.3390/ijerph7031036.
28. Grinde B, Patil GG. Biophilia: does visual contact with nature impact on health and well-being?. International Journal of Environmental Research and Public Health. 2009;6(9):2332-43. https://doi.org/10.3390/ijerph6092332
29. Standish RJ, Hobbs RJ, Miller JR. Improving city life: options for ecological restoration in urban landscapes and how these might influence interactions between people and nature. Landscape Ecology. 2013;28:1213-21. https://doi.org/10.1007/s10980-012-9752-1
30. Goddard MA, Dougill AJ, Benton TG. Scaling up from gardens: biodiversity conservation in urban environments. Trends in Ecology & Evolution. 2010;25(2):90-8. https://doi.org/10.1016/j.tree.2009.07.016
31. Hussein H. Using the sensory garden as a tool to enhance the educational development and social interaction of children with special needs. Support Learn. 2010;25(1):25-31. https://doi.org/10.1111/j.1467-9604.2009.01435.x
32. Davis AP, Hunt WF, Traver RG, Clar M. Bioretention technology: Overview of current practice and future needs. Journal of Environmental Engineering. 2009;135(3):109-17. https://doi.org/10.1061/(ASCE)0733-9372(2009)135:3(109)
33. Fjørtoft I. Landscape as playscape: The effects of natural environments on children's play and motor development. Child

Youth Environ. 2004;14(2):21-44. https://www.jstor.org/stable/10.7721/chilyoutenvi.14.2.0021

34. Ulrich RS. Health benefits of gardens in hospitals. InPaper for conference, Plants for People International Exhibition Floriade 2002 Apr 6 (Vol. 17, No. 5, p. 2010).
35. Ignatieva M, Stewart GH, Meurk C. Planning and design of ecological networks in urban areas. Landscape and Ecological Engineering. 2011;7:17-25. https://doi.org/10.1007/s11355-010-0143-y
36. Nowak DJ, Crane DE, Stevens JC. Air pollution removal by urban trees and shrubs in the United States. Urban For Urban Green. 2006;4(3-4):115-23. https://doi.org/10.1016/j.ufug.2006.01.007
37. Carrus G, Scopelliti M, Lafortezza R, Colangelo G, Ferrini F, Salbitano F, et al. Go greener, feel better? The positive effects of biodiversity on the well-being of individuals visiting urban and peri-urban green areas. Landscape and urban planning. 2015;134:221-8. https://doi.org/10.1016/j.landurbplan.2014.10.022
38. Demuzere M, Orru K, Heidrich O, Olazabal E, Geneletti D, Orru H, et al. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management. 2014;146:107-15. https://doi.org/10.1016/j.jenvman.2014.07.025
39. Newman P. Biophilic urbanism: a case study on Singapore. Australian Planner. 2014;51(1):47-65. https://doi.org/10.1080/07293682.2013.790832
40. Beatley T. Handbook of biophilic city planning and design. Island Press; 2016.
41. Figueiro MG, Steverson B, Heerwagen J, Kampschroer K, Hunter CM, Gonzales K, et al. The impact of daytime light exposures on sleep and mood in office workers. Sleep Health. 2017;3(3):204-15. https://doi.org/10.1016/j.sleh.2017.03.005
42. Madre F, Vergnes A, Machon N, Clergeau P. Green roofs as habitats for wild plant species in urban landscapes: First insights from a large-scale sampling. Landscape and Urban Planning. 2014;122:100-7. https://doi.org/10.1016/j.landurbplan.2013.11.012
43. Chirisa I. Building and urban planning in Zimbabwe with special reference to Harare: Putting needs, costs and sustainability in focus. Consilience. 2014(11):1-26.
44. Depledge MH, Stone RJ, Bird WJ. Can natural and virtual environments be used to promote improved human health and wellbeing?. Environmental Science & Technology. 2011;45(11):4660-5.
45. Ghaffarianhoseini A, AlWaer H, Omrany H, Ghaffarianhoseini A, Alalouch C, Clements-Croome D, et al. Sick building syndrome: are we doing enough?. Architectural Science Review. 2018;61(3):99-121. https://doi.org/10.1080/00038628.2018.1461060
46. Kim KH. Beyond green: growing algae facade. InARCC Conference Repository 2013. https://doi.org/10.17831/rep:arcc%25y211
47. Lau SS, Gou Z, Liu Y. Healthy campus by open space design: Approaches and guidelines. Frontiers of Architectural Research. 2014;3(4):452-67. https://doi.org/10.1016/j.foar.2014.06.006
48. Eick J. Showcase: The Bullitt Center. High Perform Build. 2013:37-46.
49. Giacomello E, Valagussa M. Vertical. 2015.
50. Mato BU, Sinha S. Environmental Impact of Biophilic Architecture on Human Health: Evidence from Residential Buildings Greater Noida, India.
51. Largo-Wight E, Chen WW, Dodd V, Weiler R. Healthy workplaces: The effects of nature contact at work on employee stress and health. Public Health Reports. 2011;126(1_suppl):124-30. https://doi.org/10.1177/00333549111260S116
52. Park BJ, Tsunetsugu Y, Kasetani T, Kagawa T, Miyazaki Y. The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): evidence from field experiments in 24 forests across Japan. Environmental health and preventive medicine. 2010;15:18-26. https://doi.org/10.1007/s12199-009-0086-9n
53. Wolverton BC, Johnson A, Bounds K. Interior landscape plants for indoor air pollution abatement. NASA; 1989.
54. Bratman GN, Hamilton JP, Hahn KS, Daily GC, Gross JJ. Nature experience reduces rumination and subgenual prefrontal cortex activation. Proceedings of the national academy of sciences. 2015;112(28):8567-72. https://doi.org/10.1073/pnas.1510459112
55. Heschong L. Windows and office worker performance. Creating the Productive Workplace; Taylor & Francis: London, UK. 2006:277.
56. Atchley RA, Strayer DL, Atchley P. Creativity in the wild: Improving creative reasoning through immersion in natural settings. PLoS One. 2012;7(12):e51474. https://doi.org/10.1371/journal.pone.0051474
57. Tanner CK. Effects of school design on student outcomes. Journal of Educational Administration. 2009;47(3):381-99. https://doi.org/10.1108/09578230910955809
58. Skelhorn C, Lindley S, Levermore G. The impact of vegetation types on air and surface temperatures in a temperate city: A fine scale assessment in Manchester, UK. Landscape and Urban Planning. 2014;121:129-40. https://doi.org/10.1016/j.landurbplan.2013.09.012
59. Philadelphia Water Department. Green City, Clean Waters: The City of Philadelphia's Program for Combined Sewer Overflow Control. Philadelphia Water Department; 2011.
60. Zari MP. Regenerative urban design and ecosystem biomimicry. Routledge; 2018.
61. Liu K, Baskaran B. Thermal performance of green roofs through field evaluation. Proc North American green roof infrastructure conference. 2003:1-10.
62. Wolf KL. Business district streetscapes, trees and consumer response. Journal of Forestry. 2005;103(8):396-400. https://doi.org/10.1093/jof/103.8.396
63. Yen TS. The practice of integrated design: The case study of Khoo Teck Puat Hospital, Singapore. MSc Sustainable Building Design, BCA Academy, University of Nottingham; 2012.
64. Crompton JL. The impact of parks on property values: empirical evidence from the past two decades in the United States. Managing Leisure. 2005;10(4):203-18. https://doi.org/10.1080/13606710500348060
65. Peck SW, Kuhn ME. Design guidelines for green roofs. Ontario Association of Architects; 2003.
66. Terrapin Bright Green. The Economics of Biophilia. Terrapin Bright Green LLC; 2012.
67. NASA. Growing Plants in Space. Available from: https://www.nasa.gov/content/growing-plants-in-space. 2019.
68. Ozdemir H. Integrating Nature into Academic Spaces: Biophilic Campus. PLANARCH-Design and Planning Research. 2024;8(2):210-24. https://doi.org/10.54864/planarch.1491955
69. Ulrich RS, Simons RF, Losito BD, Fiorito E, Miles MA, Zelson M. Stress recovery during exposure to natural and urban environments. Journal of Environmental Psychology. 1991;11(3):201-30. https://doi.org/10.1016/S0272-4944(05)80184-7
70. Berman MG, Jonides J, Kaplan S. The cognitive benefits of interacting with nature. Psychological science. 2008;19(12):1207-12. https://doi.org/10.1111/j.1467-9280.2008.02225
71. Thompson Coon J, Boddy K, Stein K, Whear R, Barton J, Depledge MH. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. Environmental science & technology. 2011;45(5):1761-72. https://doi.org/10.1021/es102947t

72. Biophilic Approach Model for Urban Design, Lost Spaces - Scientific Figure on ResearchGate. https://www.researchgate.net/figure/Courtesy-of-international-living-future-institute-url-3-Nature-Of-The-Space_fig4_357097267

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (https://creativecommons.org/licenses/by/4.0/)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.