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Biophilic Smart Cities: Harnessing Urban Green Spaces for Health and Well-being in Connected Environments

* **Amal Bouaziz**
Higher institute of arts and crafts of sfax, University of Sfax, Sfax Tunisia
E-mail: amal-bouaziz@hotmail
ORCID: https://orcid.org/0009-0007-0033-9548

A B S T R A C T

The concept of biophilic smart cities centers on blending advanced technologies with biophilic design to improve urban living. In this model, urban green spaces play a key role, providing aesthetic value while simultaneously supporting physical, mental, and social well-being. This study employs a qualitative approach based on literature review, analysis of international case studies, and evaluation of planning documents related to urban development in Tunisia. The research specifically explores how the principles of biophilic smart cities can be adapted to the Tunisian context, with a focus on emerging projects such as Tunisia Garden City. By comparing global strategies with local urban dynamics, this article proposes context sensitive recommendations to support healthier, more resilient, and sustainable urban environments in Tunisia.

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1. Introduction

Modern urban environments are increasingly challenged by rapid population growth, environmental degradation, and the depletion of natural resources (UN-Habitat, 2022). In response to these issues, the concept of biophilic smart cities has emerged as a compelling solution, aiming to merge biophilic design with advanced technologies to promote healthier, more sustainable, and more resilient urban living (Sung et al., 2021; Yan et al., 2022). This integrated approach recognizes the vital role of nature in human well-being and seeks to reconnect city dwellers with natural elements through intelligent, interconnected systems (Harfouch et al., 2020). Biophilic design has demonstrated significant benefits in enhancing mental health, cognitive performance, and social well-being by incorporating natural elements into the built environment (Fang et al., 2020; da Silva et al., 2021). At the same time, smart technologies offer tools for efficient urban management, including real-time environmental monitoring, resource optimization, and adaptive infrastructure (Abusaada & Elshater, 2020; Ahvenniemi et al., 2021). Despite progress in each of these domains, there remains a gap in research addressing their

*** Corresponding Author:**
Amal Bouaziz
Higher institute of arts and crafts of sfax, University of Sfax, Sfax, Tunisia
E-mail: *amal-bouaziz@hotmail*

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convergence, particularly concerning the strategic role of urban green spaces as both ecological and technological assets (Neirotti et al., 2020).

This paper investigates how the integration of nature and technology within the urban fabric can transform green spaces into multifunctional systems that support physical, mental, and social health. The research question guiding this study is as follows: how can the integration of biophilic design and smart technologies enhance the performance of urban green spaces in fostering well-being, sustainability, and connectivity?

The objectives of the study are to examine the current contributions of urban green spaces to public health and ecological resilience, to explore how smart infrastructures can optimize their design and functionality, and to propose a conceptual framework for the development of biophilic smart cities. Aiming to answer the central question posed in the article: "How can the integration of biophilic design and technology in urban green spaces stimulate health and well-being?", this paper develops an exploratory, analytical study of various examples of urban green spaces that incorporate biophilic principles and technological innovations in their architecture. The methodological approach combines a qualitative review of relevant literature with two in depth case studies focusing on implemented or emerging examples of smart green infrastructure in Hong Kong and Singapore, followed by a presentation of qualitative results and interpretive analysis. Although recent initiatives in East Asia have explored such integrations (e.g., Singapore, Hong Kong), studies examining the applicationor even the potential of this model in African or Middle Eastern contexts remain sparse. Existing research in these regions either addresses green urbanism or digital infrastructure, but rarely both in combination (Neirotti et al., 2020).

The findings are expected to contribute new insights into how urban green spaces can be transformed through technological integration, offering guidelines for urban planners, architects, and policymakers seeking to create cities that are both intelligent and human-centered. The paper is structured to first present the theoretical foundations of biophilic and smart urbanism, followed by the methodology adopted for the study, an analysis of key findings, and a concluding discussion highlighting the broader implications of the research. Finally, while this study draws on international perspectives and case studies, it also aims to open reflections on how the biophilic smart city model could inspire future urban development in Tunisia. In the face of increasing environmental stress, urban densification, and socio-spatial inequalities, the integration of nature and technology offers a promising direction for creating healthier, more inclusive, and sustainable urban environments adapted to the Tunisian context.

2. State of the art

2.1. Biophilic Design in Urban Spaces

Urban In recent decades, the growing awareness of the psychological and physiological impacts of the built environment has renewed interest in design approaches that reconnect people with nature. One of the most influential among these is biophilic design, a concept rooted in the broader theory of biophilia a term introduced by psychologist Erich Fromm and later popularized by biologist Edward O. Wilson (1984). Derived from the Greek bios (life) and philia (love or affinity), biophilia refers to the innate human tendency to seek connections with natural forms of life and environments. Building on this, Kellert et al. (2011) articulated a theoretical framework that operationalizes biophilia through design, advocating for environments enriched with natural elements to support health, emotional balance, and cognitive functioning. Biophilic design in urban spaces involves strategies such as green roofs, living walls, natural light access, organic materials, water features, and biomorphic spatial forms. These interventions are not merely aesthetic; they have measurable effects—including reduced stress, improved mental clarity, and stronger social cohesion (Fang et al., 2020; da Silva et al., 2021). A recent contribution to this field is the Guidelines for Greening Healthcare Spaces by Bouaziz et Tur. (2023), which, although centered on hospital settings, proposes transferable principles for urban design. These include the integration of indoor greenery, natural materials, refuge spaces, locally adapted vegetation, and daylight acces all aimed at enhancing sensory comfort, cultural relevance, and psychological well-being.

2.2. Smart Urbanism and Digital Infrastructure

The concept of smart urbanism has gained traction as cities seek to address complex challenges such as demographic growth, environmental pressures, and infrastructural inefficiencies. At its core, the smart city paradigm promotes the use of digital technologie such as IoT systems, big data, artificial intelligence, and automation to optimize urban services and enhance quality of life (Neirotti et al., 2014; Ahvenniemi et al., 2021). These technologies are applied across a wide range of urban domains, including mobility, energy management, waste collection, and public safety, enabling real-time monitoring, predictive planning, and data driven governance.

2.3. Smart Ecotechnologies and Ecological Intelligence

In response to the limitations of traditional smart city frameworks, a new direction has emerged: the integration of digital intelligence with ecological systems, giving rise to what may be called smart eco-technologies. These technologies are designed not only for efficiency but also to support ecological regeneration, environmental resilience, and human-nature connectivity.

Examples of smart eco-technologies include adaptive irrigation systems based on climate data, air quality sensors embedded in green infrastructures, smart shading systems, and responsive lighting that adjusts to daylight conditions. These systems allow urban green spaces to become dynamic, multifunctional ecosystem capable of cooling urban areas, purifying air, managing storm-water, and supporting biodiversity, all while being monitored and optimized through digital tools.

Smart city models have often emphasized efficiency, control, and infrastructure optimization. However, critics point out that this techno-centric focus frequently overlooks ecological dynamics and human well-being. As a result, the early versions of smart cities tended to function more as technologically advanced systems of control rather than inclusive and resilient urban environments.

3. Methodology

This study explores how biophilic design and smart technologies shape urban sustainability, public health, and social connectedness. Using a mixed methods approach, it begins with an in depth literature review to highlight key trends and theoretical frameworks around biophilic principles and smart urban innovation. Through real world case studies, it examines how these elements are implemented in urban settings and assesses their impact on community well-being and environmental performance. Data is gathered through surveys and field observations to evaluate effects on residents' health, social interaction, and ecological sustainability. The analysis combines thematic exploration, and comparative evaluation to draw meaningful insights from the findings.

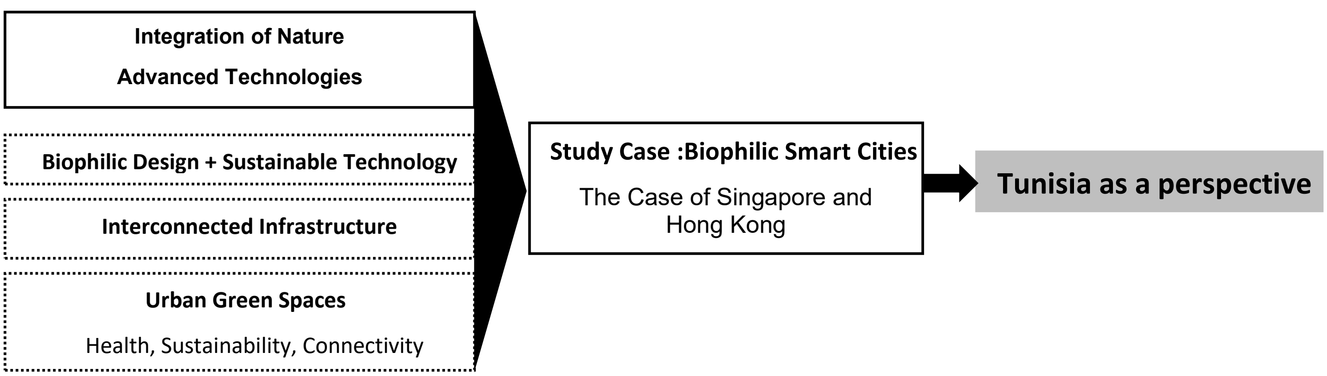

Figure 1. Structure of the study.

4. Study Design and Setting

The concept of biophilic smart cities, which integrates biophilic design principles with smart technologies, is rooted in a range of academic disciplines, including urban planning, environmental psychology, sustainability, and technology. A comprehensive literature review was conducted to establish the theoretical and empirical foundations for this study, focusing on four key areas: biophilic design, smart cities, health and sustainability, and case studies of successful urban models.

Biophilic design refers to the architectural and urban planning principles that incorporate elements of nature into built environments to promote human well-being. The term "biophilia," coined by Edward O. Wilson in the 1980s, describes humans' inherent affinity for nature and the positive impacts that nature exposure can have on physical and mental health (Wilson, 1984). Biophilic design is based on the idea that reconnecting urban residents with nature can lead to improved psychological outcomes such as reduced stress, enhanced mood, and better cognitive function (Kellert et al., 2011).

Multiple studies have demonstrated the effectiveness of biophilic design in enhancing urban environments. For example, a study by Barton et al. (2009) emphasized that access to nature and green spaces in urban settings significantly reduces stress and promotes recovery from mental fatigue. Kaplan and Kaplan (1989) also found that exposure to natural environments helps reduce cognitive load and promotes restorative experiences. The inclusion of natural elements, such as plants, water features, and green spaces, has been shown to create environments that encourage relaxation, creativity, and social interaction (Ulrich, 1984). In the context of smart cities, biophilic design integrates these principles into urban spaces while leveraging technology to monitor and optimize the benefits of natural elements (Beatley, 2011).

Smart cities refer to urban areas that leverage advanced technologies to enhance the quality of life for residents, improve the efficiency of urban systems, and promote sustainability. Technologies like Internet of Things (IoT) sensors, big data analytics, and artificial intelligence (AI) play a key role in monitoring and managing urban environments. These technologies help cities make data-driven decisions to optimize resource use, improve air quality, and reduce energy consumption (Batty et al., 2012).

According to Harrison et al. (2010), smart cities use sensors and data systems to collect real-time information on various parameters such as traffic flow, waste management, energy use, and environmental conditions. This data allows city officials to make informed decisions that improve urban efficiency, reduce carbon emissions, and enhance sustainability. Smart grids, for instance, enable real-time adjustments to electricity consumption based on demand, improving energy efficiency and reducing greenhouse gas emissions (Murray et al., 2015).

Furthermore, smart city technologies can facilitate the integration of green infrastructure in urban planning. Smart systems can monitor urban heat islands, air quality, and energy use in real-time, thereby enhancing the ability to manage green spaces more effectively and optimize their environmental benefits (Zhou et al., 2020). Thus, the combination of biophilic design and smart technologies in urban settings has the potential to create more sustainable, resilient, and livable cities.

The concept of smart cities has evolved significantly over the past few years, with a growing emphasis on the integration of advanced technologies and data driven decision making to improve urban living. A smart city leverages technologies such as Internet of Things (IoT), big data analytics, artificial intelligence (AI), and sustainable infrastructure to enhance the efficiency, sustainability, and livability of urban environments. The integration of these technologies into urban systems aims to address the challenges of rapid urbanization, resource management, pollution, and climate change, while simultaneously enhancing the quality of life for residents.

A central feature of smart cities is the deployment of IoT sensors that collect real-time data on various urban parameters, such as traffic flow, air quality, energy consumption, and waste management. This data is processed and analyzed using big data and AI to optimize the functioning of city systems. Recent studies by Zhao et al. (2023) and Tan et al. (2024) emphasized how IoT networks in smart cities enable better urban planning by providing real-time insights into environmental conditions, transportation patterns, and infrastructure needs. These innovations allow cities to become more efficient in managing resources and responding to environmental challenges.

For example, smart grids, which use IoT sensors and data analytics, enable cities to monitor and manage electricity consumption more efficiently. By dynamically adjusting power distribution based on real-time demand, smart grids reduce energy waste and lower carbon emissions (Schaeffer et al., 2020). Additionally, smart water management systems use sensors to monitor water quality, detect leaks, and optimize irrigation schedules in urban landscapes, contributing to water conservation and sustainability (Wang et al., 2023).

Smart cities also place a significant emphasis on smart mobility systems, which aim to improve urban transportation by integrating digital technologies and innovative solutions. Autonomous vehicles (AVs), electric vehicles (EVs), and smart public transport systems are increasingly being adopted in cities to reduce traffic congestion, improve air quality, and promote sustainable transportation options (Zhang et al., 2023). A study by Sun et al. (2023) highlighted how cities like Amsterdam and Barcelona are leading the way in implementing smart transportation systems, such as electric car-sharing platforms, integrated public transport apps, and autonomous bus services.

Sustainability is at the core of smart city initiatives, with a focus on reducing energy consumption and minimizing environmental impact. Smart buildings and green infrastructure are being integrated into cities to improve energy efficiency and enhance environmental quality. Smart buildings use IoT sensors to regulate temperature, lighting, and air quality, optimizing energy use and reducing operational costs. Green roofs, solar panels, and other sustainable technologies are being incorporated into building designs to further reduce the carbon footprint of urban environments (Tian et al., 2022).

An emerging trend in smart cities is the focus on smart governance, which leverages technology to improve urban management and citizen engagement. By integrating e-governance platforms and digital citizen services, cities can streamline administrative processes and improve public service delivery. The use of open data platforms allows residents to access real time information about city services, such as waste collection schedules, air quality levels, and traffic conditions (Lee et al., 2021).

The study also explored a variety of indicators related to different urban scales and biophilic design patterns. The article by Turki, Bouaziz, Taieb, and Gargouri (2023) highlights the importance of Biophilic Design Patterns, illustrating how creating visual connections with nature and incorporating natural elements into healthcare spaces contribute to a therapeutic and calming environment. A subset of these indicators was chosen for the research, focusing on aspects such as urban resilience, disaster response, and public health, all within the context of the urban environment, as shown in Fig. 2.

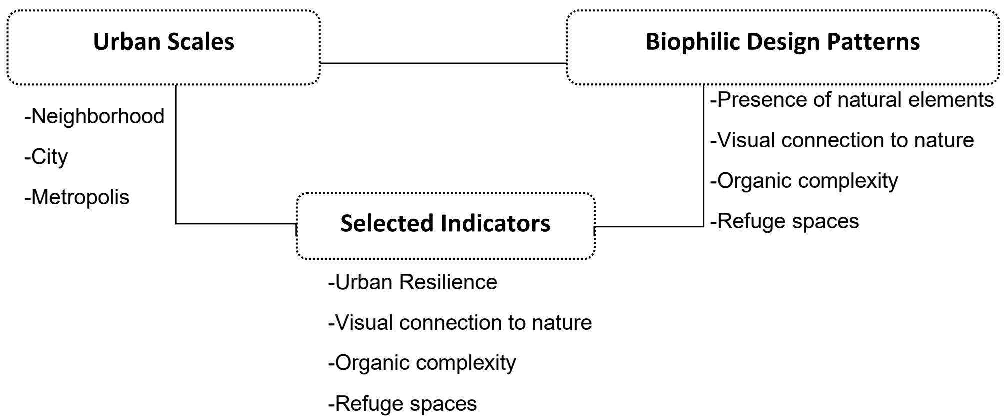

Figure 2. Connection between Urban Scales, Biophilic Design Patterns, and Sustainability Indicators.

Citizen engagement is another important aspect of smart cities. By utilizing digital platforms, smart cities foster greater interaction between local governments and residents, enabling citizens to actively participate in decision-making processes. For instance, participatory budgeting apps and smart city dashboards allow residents to vote on urban development projects and provide feedback on city services, thus improving community involvement and transparency in governance (Kumar et al., 2023).

5. Green and Smart: Transforming Urban Landscapes in Singapore and Hong Kong

Singapore has consistently been at the forefront of integrating biophilic design and smart technologies within its urban planning framework. Its approach not only enhances the quality of life for its residents but also fosters sustainability, environmental resilience, and innovative resource management. A prime example of this is the Gardens by the Bay project, along with its smart urban farming initiatives like SkyGreens. These initiatives combine natural beauty with cutting edge technology, setting a benchmark for smart biophilic cities worldwide.

The Gardens by the Bay, which opened in 2012, is a striking example of how smart cities and biophilic design can be seamlessly integrated to create sustainable and technologically advanced urban environments. As part of Singapore's larger vision to become a smart city, the project showcases how innovation can be harnessed to improve both the quality of life for residents and the resilience of the urban ecosystem.

Figure 1. The Gardens by the Bay Exterior **Figure 2.** The Gardens by the Bay Interior

Biophilic design, which focuses on connecting people to nature within urban settings, is a central element of the Gardens. The sprawling complex, which includes features like the Supertree Grove, Flower Dome, and Cloud Forest, not only offers green spaces for recreation and relaxation but also fosters a deeper connection with the natural world. These elements serve to improve well-being, reduce stress, and enhance the mental and physical health of residents and visitors alike. As Andrew Grant, director of Grant Associates, the landscape architects for the project, stated: "The Gardens by the Bay is about reimagining what an urban park can be. Blending natural beauty with advanced technology to create a space that's both sustainable and uplifting for the community." (Grant Associates)

The design of the Gardens was led by Wilkinson Eyre Architects, with Grant Associates responsible for the landscape architecture. Together, they created a visionary blueprint that balances aesthetics, sustainability, and functionality. Simultaneously, smart city technologies have been embedded into the design of the Gardens. These include energy-efficient systems, climate responsive architecture, and smart lighting, which ensure that the space operates sustainably while offering visitors a technologically enhanced experience. For example, the Lumenbeam LBX Color Changing lights used to illuminate the waterfall within the Tropical Rainforest Conservatory are part of a sophisticated lighting system that responds dynamically to the movement of the water, contributing to the immersive experience. The ability to monitor and control lighting and energy usage ensures that the project remains environmentally responsible and efficient. User experiences also highlight the Gardens' impact. Many visitors have praised the site for its ability to evoke a sense of tranquility in the heart of a bustling city. As one visitor shared, "It's a place where you can truly escape the stress of city life, reconnecting with nature while still being surrounded by innovation. The seamless integration of the greenery and technology makes the experience feel both refreshing and futuristic."(TripAdvisor)

Through this combination of biophilic design and smart city principles, Gardens by the Bay serves as a model for other cities seeking to integrate nature with technology. The project highlights how smart technologies can be leveraged not only for operational efficiency but also to enhance the human experience within urban landscapes. By blending the best of both worlds, nature and technology, Singapore continues to set the standard for future urban developments that prioritize sustainability, innovation, and well-being.

Similarly, Jewel Changi Airport in Singapore exemplifies this harmonious blend, seamlessly combining biophilic elements with cutting-edge smart technologies to redefine urban spaces. Designed by Safdie Architects (2019), its iconic Rain Vortex—the world's tallest indoor waterfall—is not merely an architectural marvel but also a symbol of biophilic innovation, designed to evoke a sense of tranquility and connection to nature. Surrounding the waterfall is a lush indoor forest featuring over 2,000 trees and 100,000 shrubs from around the world, offering visitors an immersive experience in a natural setting.

The biophilic design of Jewel Changi Airport fosters well-being by creating a serene and refreshing environment, reducing stress for travelers and visitors. This connection to nature is further enhanced by smart technologies that ensure operational efficiency and sustainability. For instance, the Rain Vortex is part of an advanced water management system that collects and recycles rainwater for irrigation, reducing water waste while maintaining the lush greenery. The structure also incorporates energy efficient lighting and climate control systems, optimizing the indoor environment while minimizing environmental impact.

Figure 5. Jewel Changi Airport Exterior

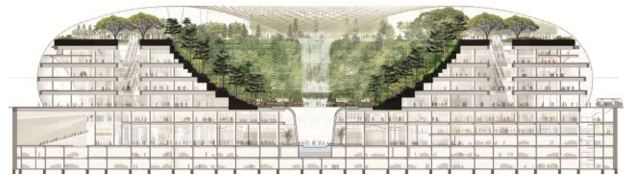

Figure 6. Interior Section of Jewel Changi Airport

Jewel Changi Airport demonstrates how smart technologies can work in tandem with biophilic principles to create spaces that are not only functional but also deeply engaging. By integrating technology to enhance the sensory experience—such as dynamic lighting that adjusts with natural rhythms and interactive installations that engage visitors the space goes beyond being a transit hub to become a destination in itself. Through projects like Gardens by the Bay and Jewel Changi Airport, Singapore continues to lead the way in urban innovation, setting a global benchmark for sustainable, nature centric developments that prioritize human well-being (Tan et al., 2020).

Hong Kong, a city known for its iconic skyline and high population density, faces numerous challenges when it comes to implementing biophilic design principles. The rapid pace of urbanization, coupled with limited land availability, creates significant obstacles for integrating nature into the urban environment. One of the primary difficulties is the city's extreme density, with over 7 million people living in a relatively small area, which places considerable pressure on available space for green infrastructure (Census and Statistics Department, 2023). This challenge is further exacerbated by the city's reliance on vertical urbanization, where high rise buildings dominate the landscape. While this vertical development offers potential for rooftop gardens and green walls, the challenge lies in designing these spaces in a way that maximizes human interaction with nature while maintaining their environmental benefits (Cheung, 2019).

In addition, Hong Kong suffers from significant air pollution, primarily due to industrial activity, vehicle emissions, and dense construction. This makes it more difficult to foster a healthy, nature integrated urban environment. Although biophilic design can play a role in mitigating some of these issues, substantial investment is required in green infrastructure and sustainable technologies, which can often be overshadowed by the city's economic priorities (Chan & Leung, 2017). Hong Kong also faces the delicate task of balancing rapid development with the preservation of its natural landscapes. Despite having numerous country parks and natural reserves, the city's rapid urban expansion has often encroached on these green spaces, creating tension between development and conservation. Ensuring that natural areas are preserved while still accommodating a growing urban population is a challenge that urban planners must address carefully (Lai, 2020).

Moreover, integrating smart technologies with nature poses additional difficulties. Hong Kong has already introduced various smart solutions aimed at improving sustainability, such as air quality sensors and energy efficient systems, but successfully combining these technologies with biophilic elements in a dense urban environment requires careful planning. The design of smart systems must complement and enhance nature based solutions rather than detract from their aesthetic or ecological value (Yung & Chan, 2020).

Despite the constraints posed by high urban density and limited land availability, Hong Kong has actively pursued the integration of biophilic principles into its urban development strategy. A flagship initiative in this regard is the Hong Kong Wetland Park, opened in 2006 in the New Territories. Spanning over 60 hectares, the park functions both as a conservation site and an educational center, offering residents access to a rich mosaic of ecosystems including wetlands, mangroves, and reedbeds within close proximity to the urban core. Although not originally conceived as a "smart" facility, the Wetland Park is embedded within a wider urban agenda that increasingly leverages technological tools for environmental management. For example, real-time monitoring systems managed by the Environmental Protection Department are deployed in adjacent protected zones to track water quality, air conditions, and biodiversity fluctuations. These systems allow for early detection of ecological disturbances and support informed conservation efforts (Environmental Protection Department, 2021).

Figure 3. Hong Kong Wetland Park Interior Site

Figure 4. Plan of Hong Kong Wetland Park.

From a user perspective, data from 2024 underscore the park's continued relevance and popularity: with over 410,000 visitors, including 8,100 international tourists, and more than 2,500 guided tours and programs conducted, it remains a key biophilic destination in the city (Hong Kong Wetland Park, 2024). Visitors consistently highlight the park's restorative ambiance and immersive natural experience, frequently describing it as a peaceful retreat from urban life. Digital exhibits and educational installations enhance this experience, using interactive technologies to foster greater awareness of local ecosystems and climate challenges. By blending natural design with technological innovation, the Hong Kong Wetland Park illustrates how urban environments even in hyper dense metropolises can be reimagined to promote ecological literacy, well-being, and sustainable coexistence between humans and nature.

In addition to large scale ecological initiatives, Hong Kong has begun to implement biophilic interventions even within its most infrastructure-heavy projects. A notable example is the Central-Wan Chai Bypass, an extensive urban expressway completed in 2019, which includes the development of green decks—elevated landscaped platforms that link key urban infrastructure with accessible green spaces. These decks not only serve as aesthetic buffers but also play an important ecological and psychological role, offering residents and commuters a more nature integrated experience in otherwise heavily built up zones (Hong Kong Highways Department, 2019).

Moreover, the Central-Wan Chai Bypass integrates several smart technologies aimed at reducing environmental impact and improving the quality of urban life. For instance, the tunnel system is equipped with automated ventilation that adjusts airflow based on real-time data on air quality, traffic conditions, and temperature, optimizing energy use and maintaining a healthy indoor environment (Hong Kong Highways Department, 2019). Additionally, IoT sensors monitor the quality of air and noise levels within and around the tunnel, providing continuous feedback for system adjustments to reduce pollution and improve urban comfort (Tang & Ho, 2018). The green decks also benefit from smart irrigation systems, which use weather and soil moisture data to efficiently water plants, helping maintain greenery while minimizing water waste (Environmental Protection Department, 2021).

Beyond infrastructure retrofitting, the city is also exploring innovative strategies to reclaim vertical surfaces for nature, including green rooftops, living walls, and urban farming projects. Given Hong Kong's limited horizontal space, these vertical green solutions have gained momentum as a way to increase biodiversity, mitigate urban heat islands, and support local food systems. Pilot programs have already been launched in schools, public buildings, and commercial towers, with some rooftops converted into automated smart farms that utilize IoT sensors to monitor soil moisture, sunlight, and temperature allowing for optimized and sustainable food production in dense urban contexts (Tang & Ho, 2018).

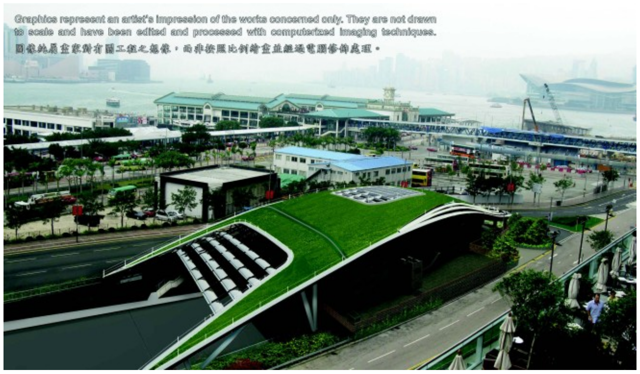

Figure 9. Aerial view of the Central Wan Chai Bypass

Figure 10. Front View of the Central Wan Chai

While the path to becoming a fully biophilic and smart city is inherently complex particularly in a metropolis defined by verticality and high land value Hong Kong is gradually redefining its urban fabric. The city's efforts to integrate nature into the built environment, supported by data driven technologies and forward thinking urban planning, represent important steps toward resilience and livability (Hong Kong Urban Renewal Authority, 2022).

Rather than viewing nature and development as opposing forces, Hong Kong is pioneering a model where urban growth coexists with ecological regeneration. Through careful spatial design, policy innovation, and smart technology integration, the city is beginning to transform its dense urban form into a more nature connected and human centered environment, ultimately paving the way for a smarter, greener, and healthier future for its residents (Environmental Protection Department, 2021).

A survey conducted by the Hong Kong Highways Department (2019) and supplemented by qualitative interviews with users reveals a positive perception of the Bypass's environment. Respondents emphasized the value of "visual openness," "green relief," and "quiet transitions" as aspects that contribute to reduced commuting fatigue and improved daily satisfaction.

For many residents, the ability to engage visually or physically with nature during routine movements is a critical factor in urban well-being. Moreover, the predictability and cleanliness of the space, enabled by connected monitoring systems, foster a sense of security and trust in public infrastructure.

6. Results

This section presents the key findings of the study, focusing on the integration of biophilic elements and smart technologies in Connected Environments. It highlights their influence on the health and well-being of residents and visitors by analyzing four notable projects: Gardens by the Bay, Jewel Changi Airport, Hong Kong Wetland Park, and the Central–Wan Chai Bypass. These cases illustrate how nature and technology can coexist in complex urban environments, offering restorative experiences and contributing to sustainable development.

Gardens by the Bay in Singapore is a large-scale urban ecological park that exemplifies how biophilic design can transform a dense city into a green sanctuary. The project integrates advanced environmental engineering, such as the cooled conservatories and the iconic Supertree Grove, which function as vertical gardens, solar energy collectors, and air exhaust systems. The Cloud Forest and Flower Dome maintain optimal temperature and humidity levels through smart climate control systems, creating comfortable microclimates year-round. Visitors report high levels of psychological comfort, reduced stress, and an enhanced sense of connection to nature. The immersive design fosters environmental awareness while providing an escape from the surrounding urban intensity. Similarly, Jewel Changi Airport in Singapore offers an innovative model for integrating nature into a high-traffic transit hub. At its center is the Rain Vortex, the world's tallest indoor waterfall, surrounded by a lush indoor forest that spans multiple levels. Smart technologies regulate light levels, indoor air quality, and temperature, creating a stable and soothing environment for travelers. These biophilic and digital systems work together to transform the airport from a purely functional space into a therapeutic environment. Visitors often describe their experience as calming and uplifting, highlighting the psychological benefits of biophilic design in non-traditional contexts such as airports. In Hong Kong, the

Wetland Park represents a successful integration of ecological preservation and public engagement. Located in the northern New Territories, this project combines natural wetlands with smart environmental monitoring systems that track biodiversity, water quality, and weather conditions. The park is both a conservation site and an educational center, where visitors are encouraged to engage directly with nature through elevated walkways, observation areas, and interactive exhibits. Feedback from users highlights the park's role in fostering mindfulness, relaxation, and environmental stewardship. By making ecological systems visible and accessible, the Wetland Park promotes both physical and mental well-being. The Central–Wan Chai Bypass, also in Hong Kong, represents a different typology, where biophilic strategies are applied to major transport infrastructure. This urban expressway includes elevated green decks and vegetated roofs that mitigate the visual and environmental impact of the tunnel system. Although primarily a mobility corridor, the bypass incorporates smart ventilation systems that respond to air quality and traffic conditions, as well as IoT sensors that monitor noise and pollution levels in real time. The landscaping above the tunnel serves as a green buffer, improving urban aesthetics and offering passive rest zones in a dense urban setting. Users and local residents benefit from enhanced air quality, lower noise levels, and visual access to greenery, all of which contribute positively to health and well-being.

Together, these four projects demonstrate that the integration of biophilic design and smart technologies can significantly enhance the quality of life in urban environments. Whether through immersive gardens, reimagined transportation infrastructure, or conservation-based public spaces, these interventions provide both ecological benefits and psychological value. They suggest that the future of urban development lies not only in high-tech innovation but also in the reconnection of people with nature through thoughtful, multisensory spatial experiences. The study shows that biophilic and smart strategies are not mutually exclusive but are, in fact, complementary tools in creating connected environments that support resilience, sustainability, and human well-being.

7. Tunisia as a Future Horizon for Biophilic Smart Cities

While global cities such as Singapore and Hong Kong have implemented advanced models of biophilic and smart infrastructure (National Parks Board Singapore, 2022; Hong Kong SAR Government, 2021), Tunisia is still in the early stages of exploring this convergence. However, the emergence of visionary projects like Tunis Garden City reflects a growing awareness of the need to reintegrate nature into urban planning and signals a broader shift toward more sustainable, human-centered development.

Although still under construction and lacking fully operational smart systems, Tunis Garden City is designed with future-oriented principles, including reduced energy consumption, promotion of walkability, and generous integration of green public spaces (Mabrouk Group, 2025). These foundational elements suggest a readiness to embrace smart ecotechnologies in future phases, positioning the project as a strategic prototype for Tunisia's transition toward biophilic-smart urbanism.

The choice of Tunisia as a focus for this perspective is not incidenta it is based on the country's urgent urban challenges and untapped potential. Rapid urbanization, water scarcity, environmental degradation, and socio-spatial inequalities have placed increasing pressure on Tunisian cities, particularly Tunis, Sfax, and Sousse. These challenges demand a rethinking of conventional planning models in favor of more resilient, inclusive, and ecologically embedded approaches.

1.At the same time, Tunisia offers fertile ground for innovation:
2.A Mediterranean climate that favors biodiversity and passive design;
3.A heritage of vernacular architecture deeply rooted in climatic and cultural intelligence;
4.A growing ecosystem of startups and designers interested in smart city solutions and green innovation;
5.Emerging public-private initiatives and international support (European Commission, 2021) for sustainable development.

By leveraging these contextual strengths, Tunisia holds the potential not only to adapt global biophilic-smart models, but also to localize them in ways that reflect its cultural identity, environmental needs, and social priorities. Projects like Tunis Garden City, even in their conceptual phase, demonstrate both the feasibility and desirability of nature-integrated, tech-enhanced urban planning.

In summary, while Tunisia's biophilic-smart infrastructure is still in its infancy, the country is well-positioned to lead regional innovation in this field. By capitalizing on its climatic advantages, architectural heritage, and emerging technological capacity (European Commission, 2021), Tunisia can pave the way toward a resilient, connected, and biophilic urban future—not only for itself, but also as a model for other North African and Middle Eastern cities.

Figure 11. Urban façade of the Tunis Garden City

Figure 12. Walk WATER and Green Boulevard.

Based on this context, supported by the literature (Kellert et al., 2008; Beatley, 2016) and the analysis of international precedents such as Gardens by the Bay and Jewel Changi Airport in Singapore (National Parks Board Singapore, 2022; Changi Airport Group, 2020), and the Central Wan Chai Bypass in Hong Kong (Hong Kong SAR Government, 2021), this study proposes a guide for integrating biophilic-smart design into Tunisian urban spaces drawing from both global expertise and local innovation capacity.

This is why, based on the literature review (Kellert et al., 2008; Beatley, 2016) and the analysis of international case studies such as Gardens by the Bay and Jewel Changi Airport in Singapore (National Parks Board Singapore, 2022; Changi Airport Group, 2020), and the Central–Wan Chai Bypass in Hong Kong (Hong Kong SAR Government, 2021), we have proposed a guide for the integration of smart biophilic design in urban spaces in Tunisia.

Table 1: A guide for the integration of smart biophilic design in urban spaces in Tunisia.

Category	Indicators/ Principles	Description/Recommandations	Application to Tunisian Context
Biophilic City	Direct Connection to Natu	Integrate local vegetation, water feature shaded areas, and natural light.	Use drought-resistant Mediterranean plant (olive trees, palms). Create green spaces i city centers.
	Natural and Sustainable Materials	Favor local materials such as stone, wood, and raw earth.	Revitalize traditional Tunisian architecture (medinas).
	Organic Patterns and Forms	Incorporate natural patterns (fractals, curves) into urban furniture and architecture.	Draw inspiration from traditional Islamic an Berber motifs.
	Urban Biodiversity	Diversify plant species to support urban fauna (insects, birds).	Promote species adapted to Mediterrane climate.
	Accessible Green Spaces	Ensure equitable and easy access to natural areas for all residents.	Create neighborhood parks in underserve districts.
Urban Resilience	Climate Adaptation	Reduce urban heat islands with vegetation and water reuse systems.	Install green roofs and walls in dense urba areas.
	Sustainable Resource Management	Optimize water and energy consumptio recycle waste.	Implement rainwater harvesting systems.
	Flexibility and Redundancy	Design multifunctional spaces that can adapt to different uses during emergencies.	Develop modular public squares and open spaces.
	Citizen Participation	Engage residents in the design and management of urban spaces.	Organize co-design workshops and ecological awareness programs.
Smart City	Environmental Monitoring Systems	IoT sensors to measure air quality, temperature, humidity, and noise.	Install sensors in parks and sensitive urban zones.
	Intelligent Infrastructure Management	Automate lighting and irrigation based on real-time conditions.	Use sensor-driven drip irrigation in parks an gardens.
	Connected Sustainable Mobility	Integrate electric transport, connected bike lanes, and shared mobility apps.	Develop bike stations and local carpoolin apps.
	Smart Energy Management	Smart grids and local renewable energy production (solar).	Install solar panels on public buildings and parking lots.
	Data Collection and Analy	Digital platforms for real-time urban dat collection and analysis.	Establish open data platforms for the city.

By following these steps, it is possible to successfully integrate smart biophilic design into urban spaces in Tunisia. This approach offers a holistic response to contemporary urban challenges by combining the restorative power of nature, the adaptability of resilient planning, and the efficiency of smart technologies. Through context-sensitive strategies that embrace Tunisia's Mediterranean climate, cultural heritage, and social dynamics, cities can evolve into healthier, more inclusive, and future-ready environments. The integration of greenery, intelligent systems, and community engagement not only improves urban well-being but also fosters a stronger connection between people and nature in the heart of Tunisian cities.

8. Conclusion

Biophilic-smart cities represent a new generation of urban ecosystems that aim to reconcile technological innovation with ecological intelligence, placing human well-being and environmental resilience at the core of urban transformation. Far from being limited to high-tech interventions, these models propose hybrid infrastructures where digital tools serve to enhance the regenerative capacities of natural systems and foster inclusive, adaptive public spaces.

Through the integration of urban green spaces as multifunctional nodes—combining environmental services, social interaction, and data-driven responsiveness—biophilic-smart cities operate at the intersection of nature, community, and technology. These spaces are not merely aesthetic amenities but act as micro-infrastructures for urban health, offering: restorative environments that promote mental and physical well-being,, platforms for environmental monitoring and adaptive urban management and frameworks for participatory use, where communities can engage with, and benefit from, intelligent and green systems.

In contexts like Tunisia, where urbanization coexists with climatic vulnerability and socio-spatial fragmentation, such an approach holds transformative potential. The development of context-sensitive, scalable prototype as seen in the conceptualization of Tunis Garden City can serve as both functional infrastructure and symbolic transition toward a more resilient and connected urban future.

As environmental infrastructure, biophilic-smart solutions support biodiversity, mitigate urban heat islands, and enable efficient management of water and air quality. As social infrastructure, they foster belonging, interaction, and accessibility, especially in neighborhoods where public space is fragmented or underdeveloped.

Future research should explore how these hybrid models can be adapted to diverse urban morphologies, particularly in the Global South. It will be essential to assess their long-term ecological performance, their integration with vernacular knowledge, and their capacity to generate socio-economic value through inclusive governance and technological equity.

Ultimately, the biophilic-smart paradigm invites us to rethink the city as a living system—one that not only responds to data but regenerates its own ecosystems, enhances the quality of urban life, and reconnects citizens to the rhythms and benefits of the natural world.

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Data availability statement
The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statements

Studies involving animal subjects: No animal studies are presented in this manuscript.
Studies involving human subjects: No human studies are presented in this manuscript.
Inclusion of identifiable human data: No potentially identifiable human images or data is presented in this study.

Conflict of Interests

The author declares no conflict of interest.

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