Forms and functions: the effect of green space geometry on community well-being

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Abstract
In the era of climate change and urbanisation, the urban forest paradigm is central to understanding resilient and sustainable cities. The forms and functions of urban greenery have evolved, embracing more creative and inclusive solutions designed to benefit the community. Industrialisation marked the first transition, moving from formal, exclusive landscapes to accessible designs promoting hygiene and collective welfare. A second transformation occurred with the fourth revolution and the COVID-19 pandemic, which highlighted the therapeutic value of green spaces for physical and mental well-being. Growing awareness of Ecosystem Services has placed green design strategies at the core of international policies.
This study investigates how the geometry and spatial distribution of greenery influence well-being and sustainability, proposing a framework of resilience indicators. The methodology includes a historical review of green space forms, a classification of horizontal and vertical urban forests, an analysis of ecosystem services, and a survey of best practices. The resulting framework, supported by literature and case studies, guides design and assessment in the built environment. Greenery conveys values, while Drawing supports its representation. Integrating parametric data into GIS- and BIM-based models opens new perspectives for mapping, monitoring, and managing green infrastructure aligned with the Digital Twin vision.

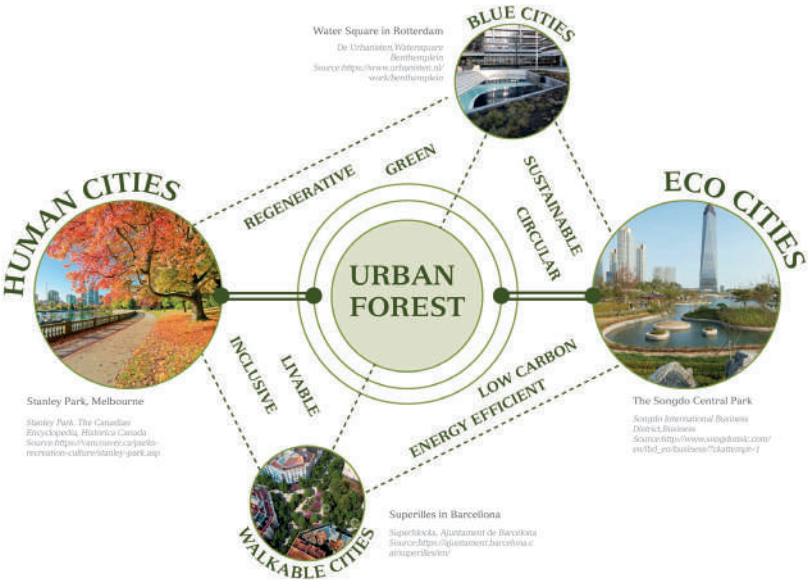
Keywords
Green design; Urban Forest bathing; Biophilia; Resilience indicators; Drawing.

ON PAGE 302:
Detail of tree bark (close-up). Photograph by Margherita Cicala.

Introduction

The world is undergoing the most significant wave of urban growth in history. Approximately 60% of the world's population now lives in cities, and the number is expected to peak at about 10.3 billion people in the mid-2080s with an increasingly older age (United Nations, 2024). Nearly 6 million square kilometres of land could be converted into urban areas by 2030 (Seto et al., 2012). Great attention worldwide is, therefore, being paid to the development of megacities not only from the point of view of land consumption and resource efficiency but also from the welfare of its citizens. The issue of human well-being had already emerged strongly between the 19th and 20th centuries concerning the increasing concentration of population in urban areas due to industrialization. Since then, several efforts have been directed in urban design policy practices to identify what relationships should exist between spaces and time devoted to work, living and recreation. As a city is more livable when it harmonizes the built environment with nature and embraces nature within its boundaries (Abbate, 2008, p.11), the role of urban greenery has begun to shift from a simple decorative element to a critical factor against grey urbanization and heavy pollution within the climate change. Thus, it becomes a carrier of values and functions.

The benefits are now well known today, and the paradigm of urban forest serves as a link to all the different interpretations of sustainable and resilient cities (Fig. 1). *Eco-Cities* (Register, 1987, pp. 3-5) incorporate green infrastructure, such as walls and parks, directly into the urban design, as in Songdo, South Korea. Numerous urban parks, covering about 40% of the city's land,



allow for the integration and preservation of biodiversity, contributing to improved air quality.
In the *Blu-Cities*, the focus is the sustainable management of water resources using integrated policies that consider the entire water cycle and its recovery and detention basins and rain gardens to reduce hydrogeological risks. Rotterdam is the most emblematic example of the water squares experiences, which allow for rainwater harvesting during intense events and, at the same time, represent multifunctional public spaces in normal weather conditions. The basis of the *Walkable City* (Speck, 2017, pp. 9-11) is the reduction of dependence on automobiles and the promotion of soft mobility, which allows for the reduction of impacts and, above all, the increase of social well-being and livability of cities.

Fig. 1. Critical role of greenery in resilient and sustainable city.

Forest Bathing

Giornale Trentino.2019. La cura? A piedi nudi nel bosco
Source:https://www.giornaletrentino.it/cronaca/non-e-sole/la-cura-a-piedi-nudi-nel-bosco-1.2099979

Festival Sviluppo Sostenibile Parma. Forest Bathing
Source:https://www.festivalsviluppsostenibile-parma.it/events/forest-bathing-unesperienza/

Harper's Bazaar. Forest Bathing: Che cos'è?
Source:https://www.harpersbazaar.com/it/cultura/a43527755/forest-bathing-che-cos-e/

Fig. 2. Forest bathing practice.

Barcelona's Superilles is an example of urban planning that promotes accessibility and sustainable mobility through the innovative use of public space organized according to street grids that form pedestrian and bicycle areas surrounded by greenery. *Human Cities* (Europen Union, 2018) uses urban greenery to create quality public spaces for the community while respecting local identity and reinforcing a sense of belonging, as in the case of Melbourne's Stanley Park. The park, with its rich flora and fauna, is a virtuous example of cultural integration and environmental preservation, where the combination of accessibility and biodiversity protection improves the quality of life in the city itself. Designing greenery in our cities becomes an opportunity to redesign the "apparently static" landscape of the urban fabric and bring it closer to the "living and dynamic" landscape of the plant world (Perini, 2013). In particular, this is an excellent opportunity to improve the quality of human life. At the beginning of the 21st century, when the rapid pace of life, constant connectivity and the incessant revolution of digital devices began to take their toll on the collective human spirit, *Forest bathing* began to re-emerge as a form of ecotherapy.

It is an ancient practice revived in Japan under the *Shinrin-yoku* name during the 1980s to respond to the increasing stress and health issues associated with urban living. It is a mindful immersion in a forest atmosphere to enhance health, wellness, and happiness (Fig. 2). Regular visits to green spaces allow people to escape urban stressors to find tranquillity and rejuvenation, even if skyscrapers surround them. This concept is not about the size but the connection quality one can forge with nature in these spaces on a deep sensory level, from the smallest pocket parks, such as a rooftop garden or a balcony full of potted plants, to extensive urban forests. It is about seeking solace in the rustle of leaves, the chirping of birds, the whisper of the wind, and the dance of sunlight through the foliage, all within the confines of the city (Brears, 2013). The growing consciousness of the demonstrated benefits of nature on mental health (Callaghan et al., 2020; Wang et al., 2022) had a significant turning point during the COVID-19 pandemic when the need to establish an interconnection between mental and physical well-being and the natural environment reaches its highest level (Fig. 3). From then on, design studies and investments in urban green spaces became indispensable.
This research aims to understand the meaningful factors of greenery in the urban fabric concerning human needs and environmental and economic sustainability to decline them into a system of resilience indicators. The methodology involves (i) the history of green spaces' geometries and functions; (ii) the categorization of horizontal and vertical urban forests; (iii) benefits provided according to the Ecosystem Services; (iv) discussion on practices; (v) definition

Milan Park Covid-19

Sky TG24. Coronavirus, nei parchi di Milano cerchi sul prato per sdraiarsi a distanza
Source:https://tg24.sky.it/cronaca/2020/05/10/coronavirus-milano-parchi#15

Fig. 3. Milan parks during pandemic.

of indicators for green spaces design to enable their evaluation and optimization.

The drawing and design of greenery over time

Urban greenery has undergone transformative dynamics over time (Fig. 4), playing an increasingly prominent role in the life of the city and its citizens today under the urban forest concept. The presence of trees in urban environments is not a recent phenomenon; their use has varied across cultures and civilizations, assuming different values (Mattogno, 2008, p. 1).

The concept of greenery originated in Mesopotamia to represent the glory of kings and the vastness of kingdoms: the hanging gardens of Babylon are recognised as one of the seven wonders of the ancient world. In the Egyptian and Hellenistic worlds, nature represented the connection with the gods. Rows of trees were used to give importance to religious sites such as temples and along processional avenues with symbolic and sacred functions. In ancient Rome, plants and vegetables were grown for food in houses in the countryside, while ornamental gardens began to be created in the Roman domus.

The *ars topiaria*, according to the writings of Pliny the Elder, was born at the very end of the first century B.C. by Gaius Matius, who first began to grow plants in plastic forms by meticulously attending to their pruning. In the Middle Ages, the *hortus conclusus*, literally walled garden, connoted the places of recollection and meditation of monasteries and abbeys, introducing vegetable gardens with beds for aromatic and medicinal herbs to flavour food and prepare healing remedies, orchards and shaded areas. However, in the later period, gardens began to take on the value of leisure-recreational space, the *garden of delights.* Located adjacent to castles or aristocratic palaces in cities, they were adorned with ornamental plants, statues and benches, pergolas, small pavilions and aviaries, configuring them as a place of imagination and artistic and literary archetype. This approach evolved in light of the new sensibility of the avant-garde environment of 15th-century Florence in the Italian garden, which found models and codified solutions for palaces or villas in Leon Battista Alberti's treatise *De Re Aedificatoria* (c. 1450). The idea that reason dominates nature is translated into a strictly geometric layout, with checkerboard motifs, rectilinear paths crossing at right angles, and trees pruned in severe forms. Order, symmetry, and balance. The garden opens the view of the landscape through careful perspective research focused on the aesthetics of urban design. Amphitheatres, labyrinths, caves adorned with shells and sophisticated-looking animals such as peacocks and swans are introduced to satisfy guests' amazement and enjoyment. Water becomes a protagonist, a dynamic decorative element with large rectangular pools, fountains,

Fig. 4. The drawing and design of greenery over time.

and artificial ponds. The setting evolves in complexity in French garden compositions, where spaces expand and perspective rises, settled during the 18th century by Chinese motifs that began to circulate due to trade initiated with the Far East. The art of the Chinese garden involves the creation of an ideal artificial landscape, a miniature of the natural one, where man and nature coexist and interact in perfect harmony. It was only with the advent of industrialization in the 19th century that public parks began to take root. This solution responded to the need to counter urbanization and combine hygienic requirements with urban decorum in an increasingly urgent civic perspective of healthy living.

The City Beautification Movement in the United States and the great urban planning transformations of European cities mark the decisive transition by hosting increasingly expanded uses aimed at collective well-being, such as pedestrian and bicycle paths, large tree-lined avenues, and park streets. Great projects marked this period: the scenic boulevards of Paris designed by Haussmann; Ludwig Ditter von Förster's wide tree-lined Ring Road in Vienna, carved out of the space resulting from the demolition of medieval ramparts; and the utopian vision of the garden city, where greenbelts surround neighbourhoods to reap the primary benefits of a country and urban environment, initiated by Ebenezer Howard in the United Kingdom. From this moment, the regulatory context also began to reflect this focus on urban quality and public green spaces by enriching its meaning over time to national (i.e. Italian M.D. 1444/1968 and Law No. 10/2013), European and international strategies such as the Aalborg Commitments, the Agenda 21 and Kyoto Protocol. However, over the years, there has been a purely quantitative drift in applying the urban standard, leading to fragmentation, marginality, lack of design and poor maintenance of green areas. Paradoxically, in the same period, the concept of the urban forest began to emerge from the literature about the environmental and ecological challenges, then finding endorsement from global institutions such as the United Nations and the World Bank in the 21st century to achieve Sustainable Development Goals. Thanks to the contributions of Von Rabitz in 1865, Le Corbusier in 1926, and Emilio Ambasz in 1970, rooftop gardens, always used in antiquity, are reaffirmed as the *Green*

over the gray technological solution (Irace, 2021) with ecological functionality and reconciliation with nature. They have become increasingly popular for managing rainwater, improving energy efficiency, improving air quality by capturing fine particulate matter and absorbing CO2 and mitigating the heat island effect (Oberndorfer et al., 2007; Susca et al., 2011; Perini et al., 2011). Additionally, they provide habitats for urban biodiversity, contributing to species conservation in densely populated areas (Getter & Rowe, 2006). The *Green architecture* of the 1990s then includes Patrick Blank's idea of the vertical garden, where the building facades integrate like a chameleon with nature by disappearing under the vegetation. From a predominantly horizontal setting, soaring only through trees, a vertical one starts to establish by amplifying the three-dimensionality and perception of the solutions. The Vertical Forest, designed by architect Stefano Boeri, represents another step forward. These residential structures with vegetation enhance urban biodiversity and the relationship between humans and nature.

Fig. 5. Greenery functions.

The approaches outlined validate the *Biophilia* (Ulrich et al., 1991) phenomenon, affirming that exposure to green spaces reduces stress, improves mood, and promotes a sense of well-being. Tracing the evolution of green spatiality (Fig. 4) and functions (Fig. 5) shows how the plurality of approaches today coexists through various mixed elements with inter-scalar dimensions that contribute to human well-being both psycho-physically and mentally.

Urban Forest Classification

In recent years, the classification of urban forests has evolved, leading to horizontal and vertical distinctions (Fig. 6). The horizontal classification focuses on the spatial distribution of green areas across the cityscape. This approach includes parks, gardens, and tree-lined avenues developed primarily along the ground surface (Fig. 7). Effective planning must take into account the connectivity of the urban landscape, defining wide and accessible spaces that create ecological corridors that foster species mobility, improve air quality and storm water management, and reduce urban heat island effects by improving cities' climate resilience (McDonald et al., 2020). They are also considered a public good promoting inclusiveness, even in highly densified and heterogeneous contexts. Examples such as Parque do Ibirapuera, The High Line and Gardens by the Bay demonstrate the transformative power of integrating large green areas to promote sustainability, biodiversity, and public health in an urban environment.
On the other hand, vertical classification refers to the distribution of green spaces along the vertical axis, incorporating elements such

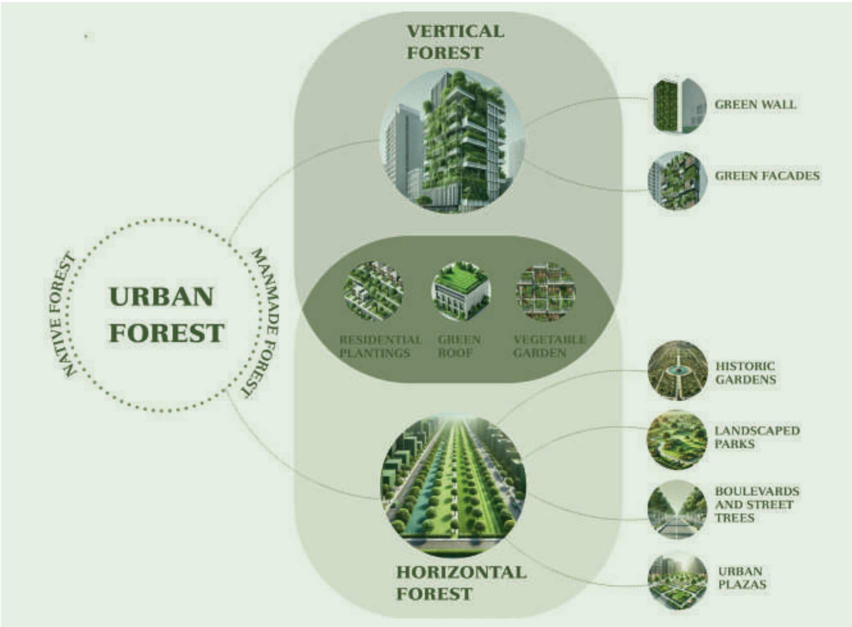


Fig. 6. Urban forest classification.

as green roofs, green walls, and the integration of trees and vegetation into buildings. This type is significant in high-density residential areas with limited horizontal space. While vertical green infrastructures significantly contribute to reducing temperatures in urban areas and improving building energy efficiency (Perini et al., 2014), they are often associated with elite architecture. Nevertheless, they represent a significant architectural innovation, helping to reduce cooling costs and enhancing the urban microclimate. Another distinctive feature is its ability to function as an ecological billboard, offering a changing panorama to the view of the metropolis. The composition of various plant species in green facades is designed to change through-

Central Park, New York City

10 Urban Parks Projects Everyone Should Know, Re-thinking the Future
Source:https://www.re-thinkingthefuture.com/designing-for-typologies/a6692-10-urban-parks-projects-everyone-should-know/

Koper Central Park, Capodistria

Koper Central Park, ArkitectureOnWeb
Source:https://www.arkitectureonweb.com/it/-/progetti/koper-central-park

Library of the Trees, Milano

Sergio Sala/Unsplash, Gardens by the Bay,Time Out Singapore
Source:https://www.platformarchitecture.it/the-library-of-trees-a-new-form-of-public-park-in-milan/

Parque do Ibirapuera, Brasile

Editora Fórum, Assimetria de Informações, Justiça Tarifária e Implementação de Sistemas de Livre Passagem (Free Flow) nas Concessões de Rodovias
Source:https://editoraforum.com.br

The High Line, New York City

The High Line,TheHighLine.org
Source:https://www.thehighline.org/photos/by-photographer/timothy-schenck/?pages_loaded=2

Gardens by the Bay, Singapore

Sergio Sala/Unsplash, Gardens by the Bay, Time Out Singapore
Source:https://www.timeout.com

out the year, reflecting the seasonal cycles. This continuous transformation enriches the urban aesthetic and introduces a temporal dimension into architectural design, making the building a living entity constantly interacting with its surrounding environment (Köhler, 2008). Billboards are instruments of visual and environmental communication, functioning as living advertisements where nature takes centre stage (Fig. 8). In this way, the buildings transform into landmarks, capable of altering the perception of urban space and becoming a medium through which change, sustainability, and the interaction between humans and nature are communicated. Emblematic examples (Fig. 9) like the Nanjing Green Towers in China, Bosco Verticale in Milan (Liu, 2023), and the Pasona Urban Farm

Fig. 7. Horizontal forest examples.

Fig. 8. The seasons seen through the trees of the Bosco Verticale.

in Tokyo showcase the benefits of incorporating vegetation into architectural structures. These buildings, adorned with thousands of plants, create microenvironments that mimic natural forests, providing urban spaces with the benefits of forest therapy. Vertical forests can redefine urban planning by offering new models of urban development capable of mitigating environmental impact through improved air quality, reduced noise pollution and regulation of the local climate.

Residential planting, green roofs, and vegetable gardens are hybrid elements that can be applied in vertical and horizontal forests. The critical distinction lies in the continuity with the ground: in the Vertical Forest, these elements develop with vertical expansion, integrating into the architecture of buildings, while in the

Towers in Nanjing, Cina
Stefano Boeri Architetti, from the project Nanjing Vertical Forest
Source:https://www.stefanoboeriarchitetti.net/en/project/nanjing-vertical-forest/

Bosco Verticale, Milano
Stefano Boeri Architetti, from the project Bosco Verticale
Source:https://www.stefanoboeriarchitetti.net/project/bosco-verticale/

Pasona Urban Farm, Tokyo
Kono Designs, Pasona Urban Farm
Source:https://konodesigns.com/urban-farm/

Splash, Madrid
Arkitecture on Web. SPLASH - Design of a Garden
Source:https://www.arkitecturesonweb.com/en/-/videos/splash-design-of-a-garden

Eden Tower, Singapore
Amazing Architecture. EDEN Tower in Singapore by Heatherwick Studio
Source:https://amazingarchitecture.com/apartments/eden-tower-in-singapore-by-heatherwick-studio

Torre dei Cedri Losanna
Stefano Boeri Architetti. Torre dei Cedri, Losanna
Source:https://www.stefanoboeriarchitetti.net/project/la-torre-di-cedri/

Fig. 9. Vertical forest examples.

Horizontal Forest, they maintain direct contact with the soil, fostering a natural and direct interaction with the underlying ecosystem. This dual applicability demonstrates the adaptability of these green infrastructures in both man-made and natural environments.

Effects and benefits

The previously described functions (Fig. 5) that have gradually emerged over time about both practice and international regulations point toward the understanding that the most significant outcome of a sustainable urban forest is to maintain a maximum level of net environmental-ecological, social, and economic (Fig. 10) benefits today and for future generations (Clark, 1997, p.1). This idea has gained ground in the literature in recent decades under the concept of *Ecosystem Services*, which represent the processes through which natural ecosystems sup-

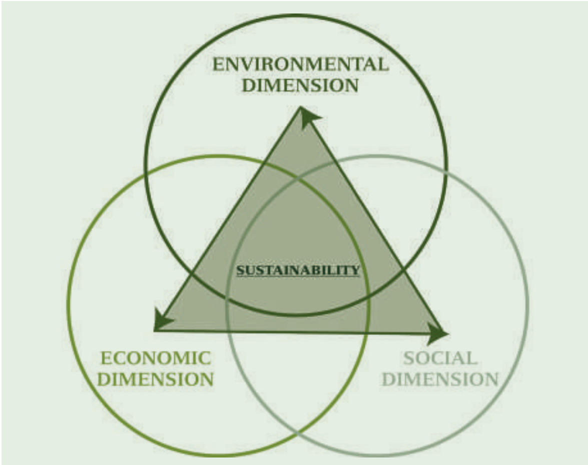


Fig. 10. Sustainability pyramid.

port and satisfy human needs, including climate regulation, air and water purification, biodiversity conservation, and the provision of spaces for recreation and mental health (Millennium Ecosystem Assessment, 2005). *Nature-based solutions* are a valuable tool in increasing urban systems' sustainability, restoring degraded ecosystems, implementing adaptive and mitigation actions concerning climate change, and improving risk management and resilience (European Commission, 2015). Therefore, well-being is assessed regarding the benefits of green on individuals, in an intimate and private dimension, and on the community. An overview of the critical effects of the three macro-areas is depicted in Figure 11.

According to the ecological component, the green area becomes an integral part of a larger macro-system with which it interacts through a continuous exchange of matter (gaseous exchange, transpiration of water vapour, absorp-

tion of dust and heavy metals) and energy (absorption of solar radiation, the transformation of light energy into organic matter) (Sanesi, Lafortezza, 2002, p. 113). One of the most essential benefits is the ability to mitigate the growing impacts of climate change. Through evapotranspiration, vegetated surfaces reduce the built environment temperatures and the urban heat island effect, improving thermal comfort for residents (Bowler et al., 2010). Additionally, such surfaces help manage water resources sustainably (Berardi et al., 2014), even in the case of extreme events. Green oases serve as vital lungs for our urban environments, absorbing carbon dioxide, filtering pollutants, and providing a habitat for various flora and fauna.
Promoting biodiversity is critical to contributing to global conservation efforts. The vertical forest

Fig. 11. Effects and benefits of urban forest.

architecture prototypes this approach by placing the relationship between humans and other living species at the centre. As their species richness and diversity are negatively affected by increasing fractions of sealed areas or buildings, birds are often chosen as indicators of habitat quality to study the ecological effect of urbanization. A well-balanced mixture of coniferous and deciduous woody plants optimizes vertical vegetation structure and represents the most effective long-term measure (Fontana et al., 2011, p. 1). However, Bird Garden is a creative, avant-garde, and sustainable response to enjoy permanent and migratory birds. Nests, perches, and feeding areas in an environment with spontaneous vegetation and autochthonous essences provide habitats and hotspots for refuge and resources for wildlife, including a wide range of species, from birds to insects, small mammals to microorganisms.
This cohabitation contributes to the food chain and cyclicity of urban ecosystems. There are various types, and with a bit of planning, they can be implemented in any setting, from home terraces to villa or museum gardens (Fig. 12). The presence of birds in cities also contributes to mental well-being: watching birds fly and listening to their song provides moments of tranquillity and contemplation. While increasing vertical greenery favours wildlife, residential planting must be carefully considered to maintain the wellness of domestic animals. Some problems can occur due to environmental enrichment of their habitat, such as being bitten by numerous insects gravitating around flowers or eating leaves containing toxic substances (e.g., cyclamens, azaleas, geraniums, calla lily). Lavender, on the other hand, releases a relaxing substance.

Environmental benefits also contribute positively to the economy through direct savings, earnings, and indirect gains. Green spaces lead to energy savings, reduce the demand for cooling air and heating, and contribute to stormwater management. Increasingly attractive and technological solutions are also used in urban design to enable additional renewable sources, such as solar or wind trees (Fig.13). Urban forestry promotes an active lifestyle among residents and consumers and creates job opportunities, from design to planting and maintenance.

Fig. 12. Bird garden examples.

Wind Trees
New World Wind: Alberi del vento per produrre energia nelle città, CityNext
Source:https://citynext.it/2023/12/11/new-world-wind-alberi-del-vento-per-produrre-energia-nelle-citta/

Solar Trees
Alberi solari: cosa sono e come funzionano, Il Digitale
Source:https://www.ildigitale.it/alberi-solari-cosa-sono-e-come-funzionano/

Urban Furniture
Design sostenibile e arredo urbano, Giwa
Source:https://www.giwa.it/design-sostenibile-e-arredo-urbano/

Fig. 13. Integration of technology in green design.

Furthermore, greenery in the neighbourhood increases property values and provides favourable environments for business, shopping, tourism, and recreation.
Healthcare savings can be achieved by providing space for outdoor sports and forest bathing. All our senses find a new vitality in the forest (Fig. 14), improving physical and mental health. The forest is a visual feast with a kaleidoscope of colours, shapes, and patterns that remind us of the beauty and complexity of nature. Listening to the forest's symphony positively influences the nervous system, reducing cortisol levels and activating the parasympathetic system associated with calm and relaxation. Smelling the aromas calls us back to multiple narratives. Inhaling phytoncides, volatile organic compounds released by trees and plants, release a series of responses to the body: heart rate and blood pressure are reduced, stress hormones are lowered, and the immune system is boosted. Touch also amplifies the experience through contact with the textured canvas: the soft moss-covered forest floor, the crunch of fallen leaves, the solidity of rocks, and the rustle of damp earth. The taste of the forest is varied and complex, a delicate balance of sweet, bitter, tangy, and earthy

notes that dance on the tongue and awaken the senses (Rohan, 2023, p. 38). Forest bathing has been recognised in healthcare, education, and business (Fig. 15) for its therapeutic benefits and value. Medical professionals and therapists have begun incorporating it into treatment plans, acknowledging the healing power of nature for the recovery and well-being of patients. Indeed, it has been established that contact with the natural environment generates numerous mental health benefits, from improved mood to reduced perception of stress (Bratman et al., 2012). Its psychophysiological effects, such as changes in cortisol levels and heart rate, are also well known (Mygind et al., 2021). Furthermore, proximity to nature promotes better mental health (Gascón et al., 2015) and reduces psychopathological symptoms, such as depression (Bal-

Fig. 14. The forest's healing touch.

Healthcare **Education** **Business**

New Hospital, Cremona
Pambianco News. Mario Cucinella firma il Nuovo Ospedale di Cremona
Source:https://realestate.pambianconews.com/2023/12/19/mario-cucinella-firma-il-nuovo-ospedale-di-cremona/

Prestige University, Indore
The Plan. Prestige University. Sanjay Puri Architects
Source:https://www.theplan.it/eng/award-2019-Education/prestige-university

Green Factory, Parma
Designboom. Green factory by Iotti + Pavarani settles within cultivated plain in northern Italy
Source:https://www.designboom.com/architecture/iotti-pavarani-industrial-green-factory-within-cultivated-plain-northern-italy-06-19-2020/

Fig. 15. Forest bathing in healthcare, education, and business contexts.

anzá-Martínez and Cervera-Martínez, 2022). These studies have led to the reintroduction of greenery in everyday life contexts. Schools have started to introduce outdoor classrooms and nature-based learning experiences, promoting care for nature in the younger generation.
Also in the workplace, companies started to realise the importance of employee well-being and the role of nature in promoting productivity by introducing areas that allow them to switch off and retrieve inspiration, insight, strength and serenity.

Discussion on practice

Despite the undeniable benefits, not all urban green integration projects have the expected benefit as their primary purpose, especially in their vertical conformation. Modern-day vertical greenery seems to have inherited the aesthetic tradition and the exclusivity of Babylonian hanging gardens, although presented with a new narrative related to sustainability and urban forestation. Some examples, such as the Bosco Verticale, present several critical issues, as they depend on external professionals for expensive maintenance and the distinctive-

Vertical Forest Maintenance

Milano, giardinieri volanti. La Repubblica, October 3, 2015
Source https://milano.repubblica.it/cronaca/2015/10/03/foto/milano_giardinieri_volanti-124234208/1/

ness of the greenery itself. This aspect can limit personal interaction with nature, reducing the potential well-being resulting from the perception of green as a decorative or luxury element destined only for a small elite.

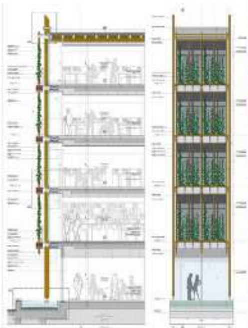
This scenario emphasises the need to balance architectural innovation and practicality, in which urban greenery can be aesthetic, functional, and easily managed by residents.

The effectiveness of projects is therefore to be assessed taking into account the economic, social and practical implications by considering whether the prevailing interests are community or individual niche. It is relevant to understand the long-term sustainability of solutions where complex irrigation, pruning and monitoring systems are required, often requiring the intervention of specialised professionals (Alter, 2013) (Fig. 16). Green elements are used in some applications as green wrapping to disguise architecture that is not as sustainable as one would have us believe. It is often considered an advantageous option to use native plants, which, adapted to the local climate and conditions, generally require less water, fertilizers and phytosanitary treatments than exotic species to address economic issues and improve ecological resilience.

Fig. 16. Vertical Forest Maintenance.

Parkroyal Collection, Singapore

Sky TG24. "Coronavirus, nei parchi di Milano cerchi sul prato per stare a distanza. Source: https://tg24.sky.it/cronaca/2020/05/10/coronavirus-milano-parchi#15



Quartiere Le Albere, Trento

Progetto Storia dell'Arte. Il MUSE di Renzo Piano a Trento Source:https://www.progettostoriadellarte.it/2021/04/27/il-muse-di-renzo-piano-a-trento/

Edilportale. Zintek® per il quartiere Le Albere di Trento, progettato da Renzo Piano Source:https://www.edilportale.com/news/2012/01/aziende/zintek-per-il-quartiere-le-albere-di-trento-progettato-da-renzo-piano_25549_5.html

Fig. 17. Parkroyal Collection, Singapore and Quartiere Le Albere, Trento.

This approach would lead to a significant reduction in operating costs and greater sustainability of the project in the long term. However, adopting native plants is difficult, especially in complex architectural environments like vertical forests. These plants may only partially meet the required aesthetic and structural needs due to their poor growth capacity in limited space conditions or the absence of desired ornamental features (Francis et al., 2011). Another possible solution could be to promote participatory management by involving residents in the care of green areas. According to some studies, even in complex contexts such as vertical forests, residents can effectively participate in the maintenance of urban greenery with adequate training and technical support, reducing maintenance costs and increasing residents' sense of community and well-being (Kondo et al., 2018). Concrete examples of projects that have attempted to make vertical greenery more economically sustainable include the Parkroyal Collection in Singapore (Fig. 17). Here, the hydroponic system allows a considerable reduction in maintenance costs, thanks to native tropical plants that can adapt to the climate. Similarly, the Albere project in Trento (Fig. 17) exploits a more straightforward concept of verticality, demonstrating how the integration of natural elements in façades can be economically sustainable without compromising architectural and environmental quality. These cases pave the way towards increasingly sustainable and accessible solutions that reduce costs and promote participatory management. In the case of the Homefarm project in Singapore (Fig. 18), on the other hand, the use of cultivated spaces directly on the façades of buildings provides significant environmental and social benefits in addition to the restitution of a very evocative scenario, also in terms of space, restoring an extraordinarily functional and no longer exclusively aesthetic connotation.

Drawing as a tool for green space knowledge and design

The integration of green in urban and architectural contexts requires not only technical and ecological knowledge, but also a rethinking of the way this knowledge is structured, visualised

Fig. 18. Homefarm, Singapore.

and communicated. As urban projects increasingly involve complex environmental variables, the discipline of drawing plays a key role in the representation and management of green infrastructure. In this context, representation becomes both a design tool and a conceptual lens that informs decision-making processes.

Drawing is no longer simply a visualisation instrument, but a cognitive and operational tool that supports analysis, interpretation and simulation. The complexity of green infrastructure in contemporary cities requires advanced representation systems capable of integrating spatial, environmental and temporal data. In this context, the discipline of drawing contributes to the construction of new descriptive languages and methods for green design and management, embracing a multiscalar and relational approach to spatial knowledge.

Parametric information such as vegetation height, canopy density, permeability ratio, soil type, biodiversity indices and evapotranspiration potential are increasingly integrated into representation models through gis and bim platforms. These systems allow the construction

of complex digital twins, in which urban green areas are no longer static elements but dynamic objects with behavioural rules, life cycle phases and performance data.
Through mapping tools, photogrammetry, lidar scans and satellite images, it is now possible to model the morphology and health of green areas in real time, supporting design decisions based on predictive simulations and scenario analysis. The integration of BIM and GIS, as demonstrated in the Oostplein redevelopment project in Rotterdam, exemplifies how these technologies can optimize both the design and environmental impact analysis of urban green infrastructure. BIM has played a central role in creating a detailed 3D model of the park, integrating data on materials, environmental performance, and ecosystem services. Through tools like Revit and Insight 360, it has enabled simulations of the effects of vegetation on climate mitigation, CO_2 absorption, and energy efficiency. Meanwhile, GIS has supported the project with geospatial data, mapping soil permeability, assessing ecological benefits, and analyzing noise reduction. This interoperability between BIM and GIS has allowed for a more strategic and informed urban planning process, where green infrastructure is treated not only as a design element but as a dynamic, data-driven system that interacts with its environment and evolves over time. Representation, in this sense, becomes a mediator between ecology and form, supporting both strategic planning and detailed design.
As Stefano Mancuso suggests in his book 'Fitopolis, la città vivente', cities should be redesigned as living organisms, in which each structure performs a biological function, and drawing, in this

Case study	*Indicator*	*Unit*	*Description*
Bosco Verticale *Stanley Park* *Torre dei Cedri*	CO_2 absorption	kg CO_2 /year	Amount of carbon dioxide sequestered annually
Bosco Verticale *Eden Tower* *Water Square*	Green wall surface coverage	% of building surface	Share of building exterior covered with plants.
Stanley Park	Number of fauna species observed	n°/ha	Count of different animal species recorded in the area.
Torre dei Cedri	Number of mature trees on structure	n°	Total number of large trees integrated into the building.
Water Square	Number of native species	n°/km^2	Biodiversity indicator showing richness of native species.
The High Line	Number of pollinator species	n°/ km^2	Biodiversity indicator for ecosystem health.
Green Factory	Percentage of green roof area	% of total roof surface	Extent of roof area covered by vegetation.
Water Square	Rainwater retention capacity	l/m^2	Volume of water retained by green infrastructure to reduce runoff.
Gardens by the Bay *Eden Tower*	Reduction in cooling energy demand	% kWh/year	Energy saved through passive cooling/heating
Le Albere	Reduction in heat island effect	C°	Cooling impact in urban microclimate.
Central Park	Runoff reduction	% decrease in runoff	Reduction in surface water runoff due to vegetation.
Parkroyal Collection *Stanley Park* *Water Square*	Temperature reduction	Degrees Celsius	Cooling effect of vegetation in urban environments.
Central Park *Stanley Park*	Tree canopy cover	% of total urban area	Extent of land shaded by tree foliage.
Songdo Central Park	Water retention capacity	l/ha	Ability to retain stormwater within park boundaries.

vision, becomes the narrative and analytical tool for translating natural logic into urban language.

Gardens by the Bay	Biophilic surface coverage	%	Area of biophilic elements enhancing wellbeing.
Green Factory	Employee productivity increase	%	Workplace wellness related to green features.
Stanley Park	Presence of sports/playground areas	Yes/No	Availability of recreational infrastructure.
Superilles	Reduction in NO_2 and PM levels	µg/m³	Improvement in air quality indicators.
Homefarm	Senior citizen participation	% of residents involved	Involvement of elderly in green activities.

In this way, the integration of drawing and parametric systems bridges the gap between conceptual frameworks and practical design strategies. This alignment becomes particularly relevant in the definition and application of resilience indicators, as illustrated in the following section.

Resilience indicators

From the form and function considerations discussed in the previous paragraphs, the practical experiences analysed, and previous studies (Clark, 1997; Thorén, 2000; Sanesi, Lafortezza, 2002, pp. 117-119), a series of indicators have been identified for evaluating green areas (Fig. 19). These parameters can be helpful both at the stage of knowledge and analysis of an urban context and concerning the effectiveness of a project proposal. Specifically, the Pressure-State-Response (PSR) framework (OECD, 1993) was considered, which provides a mechanism for monitoring the state of the environment and the economy.

Building upon the comparative analysis of sixteen international case studies, this section offers

Fig. 19. Environmental and Vegetative indicators.

Fig. 20. Health and Psychological Wellbeing.

Case Study	Indicator	Unit	Description
The High Line	Green coverage along railway	% of total railway transformed	Portion of infrastructure reused as green space.
Parkroyal Collection	Green space to built space ratio	% of total project area	Balance between constructed and vegetated area.
Superilles	Length of pedestrianized green areas	km	Extent of car-free green urban spaces.
Superilles	Reduction in car traffic	% decrease in vehicle count	Effect of green planning on mobility.
Le Albere	Permeable surface coverage	% of total land area	Extent of surfaces allowing water infiltration.

Fig. 21. Urbanistic indicators.

a structured framework of resilience indicators derived from observed strategies and design features in urban green infrastructure. The selected indicators reflect both qualitative and quantitative dimensions, with an emphasis on measurable impacts that relate to environmental, psychological, and urbanistic outcomes. In order to better align with the multidimensional nature of green spaces, the indicators have been classified into three macro-categories:

- **Environmental and Vegetative**, which include ecological functions such as air purification, biodiversity enhancement, and temperature regulation;
- **Health and Psychological Wellbeing**, addressing the influence of green infrastructure on

mental health, stress reduction, and indoor comfort;

• **Urbanistic**, which relates to spatial planning, green connectivity, and sustainable mobility.

The following tables present a synthesis of selected indicators by category, illustrating the diversity of strategies and potential applications in urban planning and green design.

Case study: Manifattura Tabacchi Torino and resilience-oriented design

The city of turin has emerged as a national reference in green infrastructure planning, with over 48 million square meters of green space, structured by typology and function.

Through its *piano strategico dell'infrastruttura verde*, the municipality has formalized a set of criteria for resilience, biodiversity, and public accessibility that aligns with many of the indicators proposed in this study. The document provides a concrete example of how indicator-based planning is already being implemented at the city scale, confirming the operational feasibility of such frameworks.

The former Manifattura Tabacchi in Turin offers a relevant case of adaptive reuse where green infrastructure, digital tools, and heritage transformation converge. As part of a broader urban regeneration program, the project integrates principles of environmental sustainability, public accessibility, and technological innovation.

Through the application of bim-based models, the site's morphological and material components have been digitised and analysed in correlation with climate comfort data and potential vegetation layers. The design scenario foresees the inclusion of green roofs, vertical plant sys-

CRITERIA	INDICATOR		DESCRIPTION	PSR	
	m^2/inhabitant	m^2/inhabitant	Availability per inhabitant of urban green space	P	
	Forest canopy cover by neighbourhood	[%]	The degree of coverage indicates the space occupied by the crowns in projection on the horizontal plane	S	
	Prevalent expansion	Horizontal, Vertical	Horizontal: spatial distribution in continuity with the urban landscape Vertical: spatial distribution along the vertical axis	S	
	Design solution	Street tree, Garden, Park, Vegetable garden, Green roof, Green façade, Urban forest	Prevalent or most significant design solution adopted	R	
	Cultural significance	Yes/No	Place of artistic or historical interest, or linked to local traditions and practices, or providing a sense of identity	P	TECHNOLOGY
FORM	Aesthetic appeal	High Medium Low	A well- landscaped area that contributes to the attractiveness and scenic beauty of the city	P	
	Land cover mix	High Medium Low	Diversification of land use (e.g. tree cover, shrub, herb, grass, building, paved surfaces and other)	S	
	Toxic plants	Yes/No	Presence of toxic plants for animals such as Azalea, Cactus, Cycas, Oleander, Lily of the Valley, Dieffenbachia and Lantana, Lilium and Monstera, Jasmine, Primula.	P	
	Green infrastructure connectivity index	High Medium Low	Grade of connection of urban and suburban green areas to the environmental system to promote a widespread naturalness High: > 60% green system Medium: 41-60% neighbouring areas Low: < 40% spot area	S	MANAGEMENT
	Sports	Yes/No	Presence of equipped areas for sports	P	
	Playground	Yes/No	Presence of a children's play area	P	
	Dog area	Yes/No	Presence of demarcated areas to let dogs free	P	
ACCESSIBILITY	Usability	High Medium Low	Proximity of inhabitants to green areas to ensure their real enjoyment % inhabitants living at a distance < 500 m from an area of > 6000 m^2 High: > 85% Medium: 31-85% Low: < 30%	P	
	Architectural barriers	Yes/No	Presence of architectural barriers, especially in relation to the walkability of child seats or wheelchairs	S	EDUCATION
	Level of attendance	High Medium Low	Daily attendance level by citizens	P	
ECOSYSTEM SERVICES PROVIDER	Biodiversity	High Medium Low	Capacity to host multiple habitats and diverse species (tree, plant, shrubs, flowers, and wildlife), also evaluable through the Shannon Index for the taxonomic distribution of trees	S	SAFETY
	Bird garden	Yes/No	Presence of greenways, plant and elements that favour the passage or roosting of birds	R	

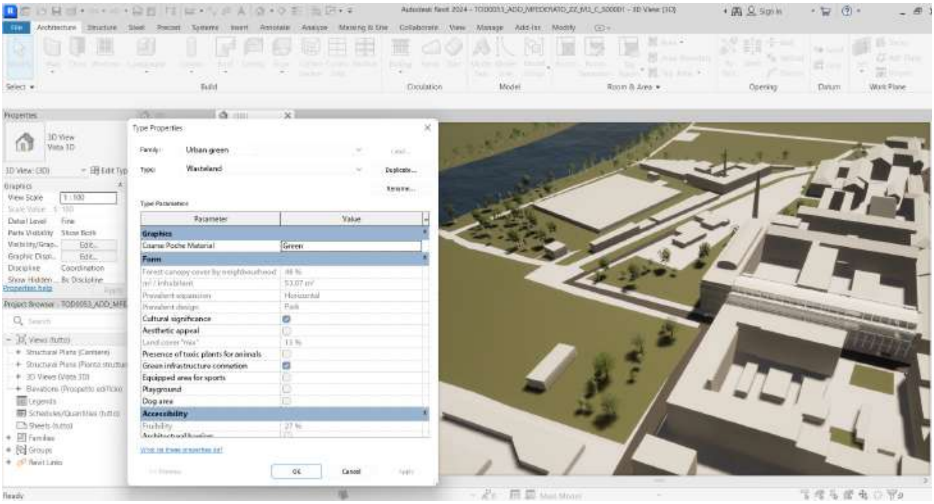
Rainwater harvesting	Yes/No	Adoption of solutions for temporary storage and release capacity such as: storm water wetlands to safely store rainwater in semi-natural areas that can flood naturally; rain gardens positioned at the edges of impermeable areas to which water can flow; storm water tree-lined drainage trenches.	R
Urban heat island mitigation	Yes/No	Adoption of solutions to mitigate urban heat islands such as: water installations, shading systems, cool materials in floor coverings	R
Renewable sources	Yes/No	Integration of renewable sources such as photovoltaic panels	R
Monitoring systems	Yes/No	Use of tool for monitoring such as remote sensing technology, drone flights, ground-based sensors, digital phenotyping	R
Data analytics	Yes/No	Presence of sophisticated software and platform for data processing	R
Greenery Registry	Yes/No	Mapping of green areas according to the Italian Law No. 10/2013, including GIS/BIM	R
Degradation	High Medium Low	State of disrepair of installed structure or furnishing elements	S
Phytosanitary state	High Medium Low	Assessment of the phytosanitary status High: excellent condition Medium: normal condition Low: critical condition with frequent dead or infestations and diseased plants	P
Management needs	High Medium Low	High: required the intervention of specialised means or procedures (rope work, special equipment) Medium: ordinary procedures Low: wasteland	P
Maintenance costs	High Medium Low	Maintenance cost in relation to the type of design solution	P
Community involvement	High Medium Low	High: participatory resource management Medium: management of city vegetable gardens Low: no or limited tools	R
Sociocultural values	Yes/No	Place suitable for recreation, physical activities, social interaction, and educational opportunities	R
Learning Paths	Yes/No	Presence of learning paths	R
Surveillance	Yes/No	Presence of video surveillance systems	R
Accidents to objects or persons	High Medium Low	Frequency of occurrence of accidents to property and persons High: frequent and widespread accidents Medium: limited and occasional accidents Low: absence of accidents	R

Fig. 22. Indicators for urban green evaluation.

tems, and permeable public spaces, aligned with the indicators described in this paper — particularly those related to thermal regulation, green surface coverage, and accessibility. The site is part of the strategic perimeter addressed by the "*Piano Strategico dell'Infrastruttura Verde*", and its digital modelling is contributing to the experimentation of digital twin environments for climate-resilient urban planning. This confirms the operational relevance of representation techniques and resilience indicators in transforming underused spaces into green, performative infrastructure.

The indicators used for this study were identified through the cross-analysis of case study documentation, literature on ecosystem services, and performance metrics already employed in urban green projects. While some derive from established frameworks (such as OECD's Pressure-State-Response model), others are extracted or adapted from direct observations in projects like the High Line in New York, Bosco Verticale in Milan, or Superilles in Barcelona.

This methodological approach was concretely applied in the thesis by Mihaela Cristina Dumbravă and Sara Rinelli, *"Systemic Assessment Approach for Urban Design. Urban Indicators for Measuring the Resilience of Cities",* supervised by Anna Osello and Francesca Maria Ugliotti (Polytechnic of Turin, Master's Degree in Architecture for Sustainability, 2024), where the project for the Manifattura Tabacchi was developed precisely through the integration and application of these urban indicators. First of all, the indicators were fundamental in the first place for analysing the actual state of the area, through the inclusion of these indicators as parameters in a



BIM model realised with Revit. Afterwards, they were used as guidelines for the design of the regeneration of the site.

Conclusions

The analysis carried out confirms how urban greenery, in its plurality of forms and functions, represents an indispensable element for the resilience and sustainability of contemporary cities. The geometry and spatial distribution of green areas profoundly influence not only environmental quality, but also the psychophysical well-being of urban communities.

The historical evolution of green areas, from aesthetic to ecosystem functions, culminates today in the need to integrate environmental design, digital technologies and social participation. Through the adoption of resilience indicators based on the Pressure-State-Response (PSR) model, urban transformations can be

Fig. 23. Implementation of resilience indicators in a BIM model. Master's thesis on the regeneration of Manifattura Tabacchi in Turin.
Thesis “Systemic Assessment Approach for Urban Design. Urban Indicators for Measuring the Resilience of Cities” by Dumbrava Cristina Mihaela and Rinelli Sara.

monitored and guided in a more systematic and conscious way. The most effective strategies are confirmed to be those that promote the multi-functionality of green spaces while ensuring accessibility, biodiversity and social inclusion. The use of advanced design tools such as GIS, BIM and Digital Twin offers concrete opportunities to improve the design, management and monitoring of green infrastructures, enhancing climate change adaptation and urban quality of life.In the light of the experiences analysed, the need to overcome merely aesthetic or elitist approaches emerges, supporting design solutions that are ecologically, economically and socially sustainable. A correct design of urban green, in its multiple forms, is thus configured not only as a response to environmental impacts, but also as an engine of urban regeneration and collective wellbeing.

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