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How outdoor and indoor green spaces affect human health: a literature review

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Keywords: Green spaces; biophilia; restorativeness; human health; forest therapy; ecosystemic services
Parole chiave: Spazi verdi; biofilia; restorativeness; salute umana; terapia forestale; servizi ecosistemici

Abstract

Background*. The analysis of the complex interactions between outdoor or indoor greenness and the health of individuals and ecosystems is a topic of current and growing interest.*
Study design. *This review aims to examine and summarise the results of studies conducted to evaluate the effects of exposure to greenness on various aspects of human health and the natural environment.*
Methods. *For this purpose, in April 2024 we searched PubMed, Web of Science, and Scopus databases, Google Scholar and specialised books.*
Results. *Evidence gathered demonstrates a remarkable correlation between exposure to outdoor and indoor greenness and the improvement of mental health, including the reduction of stress, anxiety, and depression. Contact with greenness is also associated with improvements in physical health, such as reductions in blood pressure, heart rate, and inflammation, as well as in cognitive abilities, concentration, and overall recovery.*
These benefits are recognisable both in outdoor spaces, such as urban parks, oases, and public gardens, and in indoor spaces, through the introduction of plants and nature-evoking elements in living and working environments. The presence of vegetation in indoor environments, such as offices, schools, healthcare facilities, prisons, and others, can contribute to improving the quality of social spaces, fostering communication, and collaboration, and attenuating aggressiveness and inequalities, thereby increasing employee satisfaction and work efficiency. The combination of outdoor/indoor green spaces and the well-being of the living environment includes exposure to greater biodiversity, mitigation of extreme weather events, absorption of atmospheric pollutants, attenuation of urban background noise, and increased privacy. The presence of vegetation in urban areas has a positive impact on social cohesion, promoting interpersonal interaction and facilitating the development of more cohesive and inclusive communities, thus supporting a sense of belonging and collective identity.
Conclusions*. In conclusion, these results underline the importance of considering contact with greenness as a fundamental element in promoting the psychophysical health and well-being of individuals and ecosystems, suggesting the adoption of nature-based therapies and interventions in public health policies and urban planning practices.*

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Introduction

In recent years, interest in green spaces, both indoors and outdoors, has increased rapidly. Research in the field demonstrates a growing interest in the positive effects of such spaces on human health, the urban ecosystem, and the natural environment in general. However, it is crucial to delve deeper into analyses to fully understand the impacts and maximise the benefits of this relationship between humans and nature, particularly in light of ongoing climate changes.

Climate change appears to induce a broad spectrum of adverse effects on public health, along with an increase in the risk of infectious diseases, psychiatric disorders, cancer and other diseases (1). Moreover, in recent years, extreme climate has induced a decline in greenness (2,3). Specifically, since the beginning of the century, a total of 243 large-scale vegetation decline events have been identified (2). Furthermore, the current trend highlights a simultaneous burgeoning process of global urbanisation. It is estimated that by 2050, there will be a 68% increase in urbanised areas accompanied by a rise of 2.2 billion urban residents, primarily concentrated in Africa and Asia (4). With the anticipated urbanisation surge, the importance of outdoor and indoor green spaces emerges as an updated tool for designing healthier and more habitable environments to promote more resilient and sustainable urban communities.

Nevertheless, scientific literature reveals a lack of comprehensive classification and a clear definition of green space (5). This issue primarily stems from the complexity and diversity of green spaces, which can significantly differ in size, physical characteristics, functions, and management methods. In summary, the concept of urban greenness, both outdoor and indoor, is generally conceived as green environments with vegetation presence, including mainly urban public parks, non-built and/or open areas, tree-lined streets, or areas with herbaceous and shrubby vegetation suitable for recreational activities, as well as remnants of adjacent or internal city forests (6–10). Within certain disciplines in the context of natural and life sciences, a more specific meaning is attributed to the concept of green space, associating it with protected areas such as natural reserves, conservation areas, and national parks. Definition ambiguity is particularly evident when identifying private outdoor green spaces, such as urban gardens, historic parks, urban orchards, porches, courtyards, and loggias with mixed vegetation, botanical gardens, balconies, windows, and alleys adorned with green elements, vertical gardens, or green roofs, or tree-lined streets or private passages, as well as indoor urban greenness consisting of ornamental plants, a significant element of living environments which has not been fully understood, yet (11).

Terminological ambiguity occurs both within and among disciplines, and this ambiguity makes it difficult to find meaningful understanding in published literature (5). Complexity also arises in the analysis of interactions between humans and green spaces – primarily indoors – which are arranged with digital accessories, high-definition prints, or synthetic reproductions that simulate natural greenness. In this context, the qualitative and quantitative measurement of green spaces fluctuates within the methodology applied in various studies, adapting to the research scenario and objectives.

In light of this complexity, the availability of an overview concerning the effects on human health of urban outdoor and indoor green spaces is crucial for urban designers and health professionals. Considering all of the above, the primary objective of this narrative review is to analyse the extensive range of literature available on the potential benefits for human health and the ecosystem derived from the design and conservation of green spaces, both indoor and outdoor, in living and care environments. In addition to examining the impacts on residential comfort in urban areas, we will also focus on the importance of ecosystem services offered by such spaces in combating ongoing climate changes. Furthermore, the work aims to contribute to updating sustainable urban practices focused on collective well-being, suggesting a deeper exploration of forest therapy as support for health protocols.

Methods

Given the vastness of the topic and the diversity of relevant papers, we used a narrative approach to summarise the literature, searching the following databases in April 2024: PubMed, Web of Science, Scopus, and Google Scholar. The aim was to identify scientific publications, research articles, specialised books, and other relevant documents. This methodological approach involved the use of specific keywords such as “urban greenery”, “indoor and outdoor greenery”, “green spaces”, “natural space”, “green structures”, “forest therapy”, “biophilia”, “nature therapy”, “biogenic volatile organic compounds”, “ecosystem services”, “territorial planning”, “nature-based solutions”, “heatwaves”, “climate changes”, “health”,

"well-being", "mental health", "hospital admissions", "pollen allergies" and "restorativeness".

The selection of studies followed a procedure that included title screening, abstract reading, analysis of keyword presence in the full article, searching for relationships among keywords, examination of cited literature, and consultation of cited articles. During this phase, particular attention was paid to the relevance of keywords across various disciplinary domains. The diversity of study protocols and the resulting heterogeneity of results made statistical meta-analysis impractical.

Articles that were not peer-reviewed and those that did not meet the predefined inclusion criteria (e.g., molecular biology or chemistry studies, studies specifically investigating biodiversity conservation) were excluded from the study. Additionally, extensive use was made of paper and book resources available at the library system of the University of Camerino (Italy) to ensure a higher quality of the review.

Results and discussion

This review of the scientific literature was carried out to explore the interactions and complex interplay of relationships characterising indoor and outdoor greenness, in light of current climatic and anthropological dynamics. The aim was to investigate the interactions among these components and the health and well-being of individuals, as well as the integrity of urban and natural ecosystems.

The results derived from retrieved studies were qualitatively analysed and discussed to identify the primary interactions and emerging trends concerning the effects of green exposure on human health and the natural and built environment.

How Nature and Urban Greenness, both Outdoor and Indoor, can influence Living, Health, and Human Well-being

The interaction between the environment and human health is a complex topic, and still not fully understood to date, especially when attempting to synthesise and correlate data from various disciplines. Urban green space, both indoor and outdoor, can be defined as a setting characterised by the presence of vegetation or individual plants. Interactions with green space, and their effects on human health (direct and indirect), vary based on a diverse array of experiences and variables involving social, economic, environmental, spiritual, political, and behavioural aspects of specific individual or group dynamics (Table 1).

Urban green space, both outdoor and indoor, serves as a component bridging the anthropological with the ecological dimension, and it is within this context that humans form relationships and engage in various activities, occupying and inhabiting spaces.

In this context, architecture plays a pivotal role. Architecture is a discipline that shapes space to fulfil the diverse needs of humans; evolving continuously, buildings have primarily been conceived as abstract objects or formal compositions. However, Harry F. Mallgrave, a historian of American architecture, asserted that, based on neuroscientific discoveries such as those of mirror neurons, architecture is primarily an embodied experience that encompasses the entire mind-body-environment relationship (12). In support of this, a recent umbrella review suggests that acting on the built environment has a positive impact on mental health and social inclusion (13).

Perceiving spaces is defined as establishing an empathetic relationship with them, through which our psycho-physical and emotional apparatus aligns with environmental stimuli and is influenced by them. Individuals with easy access to natural environments near their living areas are overall healthier compared with others lacking this condition.

One of the proposed guidelines is the '3–30–300 rule' for urban forestry: at least 3 well-established trees in view from every home, school, and place of work, at least a 30% tree canopy in every neighbourhood; and less than 300 m to the nearest public green space from every residence (40). The long-term indirect impacts of nearby nature also include higher satisfaction levels with one's home, work, and life in general (41).

According to John Agnew's definition of place (42), any discussion involving green space should encompass at least three notions. The first is the placement of green space within physical space. The second involves the localisation and description of as much environmental information as possible, including flora, fauna, microbiota, air quality, soil conditions, drainage systems, microclimatic conditions, and artificial structures. The last, and most significant, notion encompasses all interactions between humans and green space, reflecting how humans can utilise green space and how green space can influence their lives (43).

In recent centuries, there has been an extraordinary disengagement of humans from the natural environment. Never before in history have individuals spent so little time in physical contact with animals and plants, and the long-term consequences of such behaviour

Table 1. Green spaces' direct and indirect factors leading to beneficial effects in humans.

Type of effect	Description	Key Publications
Direct		
Psychological Well-Being and Health Improvement	Improvement of mood, reduction of stress and anxiety, and enhancement of overall mental well-being through the presence and use of green spaces	(14–21)
Attentional restoration	Improved attention span and reduction of mental fatigue through exposure to natural environments	(22,23)
Biophilia	Innate and positive connection of humans with nature, enhancing the sense of belonging and aesthetic pleasure	(24,25)
Indirect		
Reduction of air pollution	Plants in green areas can absorb air pollutants, improving air quality and reducing the risks associated with respiratory diseases	(26–31)
Noise reduction	Green areas can function as natural barriers, attenuating ambient noise levels, improving sleep quality and reducing stress associated with noise	(32,33)
Increased physical activity	The presence of parks and green areas encourages outdoor physical activity, which contributes to the prevention of chronic diseases such as obesity and cardiovascular diseases	(34–36)
Temperature reduction	Green areas can mitigate the urban heat island effect, helping reduce local temperatures and improve thermal comfort	(37–39)

are unknown (44). Some research has already demonstrated that excessive artificial stimulation and an existence spent in purely man-made environments can lead to exhaustion and a decline in vitality and health. Modern society, by its very nature, isolates people from external environmental stimuli and regular contact with nature (45,46).

There are different types and indicators of green space. Vilcins and co-workers (47) provided an overview, classifying the exposure type in passive 'indirect' (e.g., view of greenness from a window), passive 'accidental' (e.g., walking past street trees) and active 'intentional' (e.g., visiting a park), and indicators in five groups, namely 'greenness', 'open space and parklands', 'quality of parklands or open space', 'vegetation cover', and 'biodiversity', underlining the complexity of such interaction and the importance of understanding it.

An ideal context for privileged contact with nature is the search for Soplicowo. Soplicowo is an imaginary term, described by the author Adam Mickiewicz (1798-1855), in the poem Pan Tadeusz. The term is connected to the environment of the great forests of Poland including that of Bialowieza, and identifies the "place" or "lived experience", referring to the moment of direct contact with nature through an imaginative empathic experience, an intimate and profound moment to experience and in which one can participate from the perspective of another (48). This idea, theorised by Professor Franco Pedrotti (botanist, Professor Emeritus at the University of Camerino, Italy), also explains that this contact seems possible in two different forms, but the emotions experienced are always the same in both cases. The first modality refers to contact with nature in places where it manifests itself in a grandiose and exceptional way, such as a large forest, a mountain range, a cliff along the ocean coast and other pristine environments and landscapes. The second mode refers to contact with nature where it appears in minor, even very limited aspects, such as an isolated tree, a hedge, a meadow, and so on. Minor but sufficient to evoke emotions, benefits, and interests.

Soplicowo can also be interpreted as the search for a mental state through a suitable congruous contact with nature: the famous Garden of Eden, present and fundamental for all human cultures which stimulates and reconciles the relationship with the whole, inspiring, relaxing the feeling towards nature or creation (48).

The fundamental point is to observe nature in all its manifestations. However, it is necessary to know how to do it, and observing it is the simplest and most direct means to derive enjoyment from it. Seeing animals and plants adds an extra dimension; nature is valued by simply observing it, creating awareness and empathy that are the foundations of the will to preserve it (49).

The presence of nature in inhabited places also represents a spiritual connection between humans and the natural environment in which they live. Traces of such interaction are manifold and are still visible in urban environments, as well as in isolated areas, where

small remnants of ancient nature such as patches of ancient forests or monumental isolated trees are still used today as retreats for prayer and meditation, near monasteries and hermitages (50). It is hard to historically identify when and how humans began to consider green space as an architectural element to design and inhabit according to their needs. In the Western World, since the 4th century, particularly in Europe, it is conceivable to place the first green space projects, with the function of refreshment and relief, near charitable structures (hospitium), where pilgrims, orphans, disabled individuals, elderly, wanderers, sick, and insane could find accommodation, care, and relief.

Another interesting relationship between humans and green spaces lies in the built environment, both indoor and outdoor. The increasing ability of humans to utilise natural resources as a source of research and design inspiration, as well as a source of natural materials, is indeed another form of tacit synergy and often assumes worrying distortions detrimental to human health and the urban ecosystem in general.

An example of this interaction lies in the 1900 Paris Exhibition, where the architect Renè Binet, for the construction of the Monumental Gate at the main entrance to the exhibition, sought inspiration from nature, inserting the vertebrae of a dinosaur, the cells from a beehive, rams, peacocks and poppies along with other stimuli from Ernst Haeckel's studies on radiolarian protozoa (51).

It has long been debated over whether nature is friendly and comforting or hostile and indifferent; however, the approach to well-being and human health in urban environments, both indoor and outdoor, requires a non-dualistic vision ideally based on ecological ethics and the evolution of multidisciplinary techniques and knowledge (52). It follows that when men suppress or destroy living forms, they dispose of things that are not theirs, they eliminate something that they had not given or produced and will never be able to return, thus transgressing a fundamental norm of biological ethics (52).

The fundamental objective of designing and revitalising anthropic environments is to ensure that health and well-being, in all their forms, are considered inspiring muses, thus promoting the increasingly relevant approach of biophilic design (53).

Lack of residential exposure to green space may result in premature mortality. A large study estimated the premature mortality burden due to lack of and unequal residential exposure to green spaces in 978 European cities and 49 greater cities, in 31 European countries (n = 169 134 322 residents aged ≥ 20 years old). A high mortality burden could be avoided if the WHO recommendation (54) for universal access to green space was achieved in these cities. In particular, estimates indicated that meeting the WHO recommendation of access to green space could prevent 42968 (95% CI 32296–64177) deaths annually using the normalised difference vegetation index (NDVI) proxy (20% [95% CI 15–30] of deaths per 100000 inhabitants-year), which represents 2.3% (95% CI 1.7–3.4) of the total natural-cause mortality. For the % of green area (GA) proxy, 17947 (95% CI 0–35747) deaths could be prevented annually. According to these data, expanding green space could avert a significant number of natural-cause fatalities in European cities each year. This emphasizes the need for policy interventions to improve the exposure of green spaces in cities and offer local estimates of the consequences. The registered green space distribution varied between cities and was not equally distributed within cities. Among European capitals, Brussels (Kingdom of Belgium), Paris (French Republic), Copenhagen (Denmark), Athens (Hellenic Republic), Budapest (Hungary), and Riga (Republic of Latvia) showed some of the highest mortality burdens due to the lack of green space. Urban interventions aiming to increase green space could promote better health and well-being while contributing to the development of sustainable and healthy cities (55).

Moreover, a meta-analysis of cohort studies highlighted an inverse association between surrounding greenness and all-cause mortality. Particularly, the pooled hazard ratio for all-cause mortality per increment of 0.1 NDVI within a buffer of 500 m or less of an individual's residence was 0.96 (95% CI 0.94–0.97) (18).

Restorativeness of Indoor and Outdoor Green Spaces on Health and Well-being

A key term, advocated by the Kaplan spouses and originating from environmental psychology, is 'restorativeness'. This term denotes the process of enhancing psycho-physical faculties derived from the environmental characteristics in which one finds themselves. Restorativeness identifies four fundamental elements: 'being-away', which pertains to the ability to psychologically and physically distance oneself from stress; 'fascination', whereby a place is rejuvenating if it does not require effort to be observed and presents pleasant stimuli from an aesthetic and acoustic standpoint; 'coherence', which promotes places that are familiar, welcoming, and comfortable; 'compatibility', which suggests that well-being is

enhanced in places one chooses to frequent.

According to Kaplan et al. (41) the concept of 'restorativeness' refers to the degree to which an experience, environment, or process contributes to the restoration of an individual's physical, cognitive, emotional, or social resources. This concept implies the capacity of an element or activity to promote renewal, refreshment, and individual well-being.

The association between restorativeness and natural environments has been the subject of numerous studies in the field of environmental and positive psychology (56). Within the realm of health and well-being research, several scientific studies have analysed the interactions between psychophysical health and indoor and outdoor green spaces, focusing on the restoration of health and improvement of well-being as crucial indicators to assess the effectiveness of such interactions. Contact with nature promotes health and well-being, and these benefits stem from multiple phenomena attributable partly to the visualisation of natural scenes and partly to being in close contact with natural environments (44).

Moreover, a meta-analysis provided evidence of greenness exposure's beneficial effects on cardiovascular health. In particular, the analysis showed that a 0.1 increase in NDVI was significantly associated with 2-3% lower odds of event, namely cardiovascular disease mortality [OR = 0.97 (95% CI 0.96–0.99)], ischemic heart disease mortality [OR = 0.98 (95% CI 0.96–1.00)], cerebrovascular disease mortality [OR = 0.98 (95% CI 0.97–1.00)], and stroke [OR = 0.98 (95% CI 0.96–0.99)] (57). However, the authors also claimed the need for further prospective and mechanistic studies to support their conclusions.

Furthermore, a meta-analysis showed that a high green space environment was significantly associated with a decreased diabetes mellitus prevalence [OR = 0.875 (95% CI 0.859–0.891; $p < 0.001$)] and mortality [Hazard Ratio = 0.917 (95% CI 0.904–0.930; $p < 0.001$)] (58). These findings corroborated results obtained in a previous systematic review, which found that higher exposure to green spaces reduces the risk of type 2 diabetes mellitus and the risk of being obese, and increases the likelihood of physical activity (59). However, there is the possibility that research tends to assume that the mere presence of nearby green spaces corresponds to an aware and active use of them (60).

Restorativeness and Psychological Well-being

Mental health is a multidimensional component that permeates various spheres of individual life, reflecting a rich and complex area of inquiry within specialist literature. This concept has traditionally been explored through various parameters such as mood, social relationships, autonomy, as well as the sense of belonging, unity, socialisation, and peer support. Additionally, significant is the role of safe and supportive environments, the promotion of individual freedom, and the process of recovery from mental disorders or psychological distress. The nature deficit disorder theory, proposed by the pedagogue and researcher Richard Louv, demonstrates that too little connection with nature impairs well-being, causing concentration difficulties, stress, anxiety, and depression (61). The global burden of such mental disorders has been estimated. In particular, 418 million disability-adjusted life years (DALYs) could be attributable to mental disorders in 2019 (16% of global DALYs). The global economic value associated with this burden is estimated at USD 5 trillion, and corresponds, at a regional level, to about 4% of gross domestic product in Eastern sub-Saharan African countries and 8% in North American countries (62).

Scientific studies have associated psychological improvement, along with reduced levels of stress and the ability to relax, with the enhanced well-being experienced from being in a natural environment (63). Furnass discovered that the experience of nature can help strengthen the activity of the right hemisphere of the brain and restore harmony in organ functions as a whole (64). An hour-long walk in nature (e.g., urban park, garden, etc.) attenuates the harmful effects of the urban environment, potentially reducing the risk of mental disorders, via a mechanism which involves a decrease in amygdala activation (65).

According to a study conducted by the National Research Council of Italy (CNR) and Club Alpino Italiano (CAI), pre-post percentage changes in synthetic indices of moods following forest therapy sessions were as follows: anxiety (–79%), depression (–74%), hostility (–77%), energy (+13%); effort (–45%) and confusion (–56%) (66).

In outdoor green-designed environments (e.g., therapeutic gardens, orchards, urban parks), psychological recovery is accentuated in areas perceived and identified as safe to visit – although people's feelings of social safety depend on the level of urbanisation (67) – through clear architectural identity, simple design with easily identifiable paths and entrances, capable of offering atmospheres regulated based on the activities to be carried out, thus providing either a more private environment or one more suitable for socialising (63). The sense of security is further

amplified by the presence of staff to support users or provide balanced support in the activities carried out in that environment, as well as the absence of dirt or the presence of adequate lighting. However, the quality of the environmental settings – which include, in addition to what was mentioned above, esthetics, walkability, biodiversity, or the availability of social activities – is still poorly explored in scientific literature, as pointed out by a recent systematic review analysing the effect of nature exposure on children's psychological well-being (68). In this review, in which most of the selected studies yielded statistically significant but weak to moderate effects, the authors also highlighted a need for further longitudinal studies, which typically provide more robust evidence of causality than cross-sectional designs.

Restorativeness and Stress Recovery

Scientific studies concerning the relationship between health and green spaces in parks or therapeutic gardens within healthcare settings reported positive outcomes in debilitated patients and caregivers. Individuals suffering from stress-related issues such as burnout, depression, and anxiety may experience shorter periods of illness, fewer symptoms of anxiety and depression, and a higher level of well-being and recovery if they spend time or work in outdoor environments as part of their treatment (63).

Psychophysiological stress recovery is facilitated by exposure to emotional stimuli derived from natural environments, through the enhancement of positive emotions, the reduction of anger, aggression and fear (69), as well as the restoration of strength and a decrease in confusion states (70).

Restorativeness in Healthcare Settings

Restorativeness, within the context of healthcare, pertains to the capacity of environments, interventions, or processes to contribute to the recovery and well-being of individuals. In healthcare settings, fostering restorative environments plays a crucial role in promoting patient healing and enhancing the well-being of healthcare professionals (71). A study demonstrated that even a short break in outdoor and indoor green areas (such as courtyard gardens, healing gardens, terraces, and green atria) reduces stress for healthcare staff, especially during extreme emergencies such as those encountered during the COVID-19 pandemic (70).

Contact with the natural cycle allows the mind to quieten, instilling a sense of calm (72). When engaging with nature (e.g., a garden, a natural landscape, the sight of trees and animals), sensory processes are triggered, aiding individuals in relaxation by distracting from inner thoughts, general stress, and concerns. They feel grounded in the environment, regain concentration (63), reduce fear, anxiety, or nervousness, muscle tension eases, and recovery improves, especially in cases of post-operative care (73).

The benefits derived from positive stimuli through contact with nature are integral parts of the fundamental mechanisms of optimal psychophysiological recovery. Ulrich, in his studies, argued that hospitalised patients had a more favourable recovery (shorter post-operative hospital stays, lower scores of post-surgical complications, fewer negative comments from nurses, and lower intake of strong analgesics) when their windows overlooked trees rather than a brick wall of a building (19,69). In the intensive care unit context, greenness and outdoor facilities are crucial not only to improve the well-being of critically ill patients, but also of their families and caregivers (74).

In hospital environments, interactions between patients and indoor and outdoor greenness have demonstrated beneficial effects, such as the reduction of aggressive behaviour (75), better pain control, reduced anxiety, and an increased level of patient satisfaction in accepting the care protocol. Also, in hospital settings, experiences involving distraction therapy with images and sounds of nature showed a significant reduction in the quality and intensity of pain in patients undergoing painful and invasive procedures, such as flexible bronchoscopy (76) or dressing changes in patients with burns (77).

Looking out the window and intercepting nature images (e.g., trees, cultivated fields, or parks) alleviate stress symptoms such as digestive disorders and headaches, with a consequent reduced need for assistance requests (78,79). Contact with nature has shown a positive impact on blood pressure and cholesterol, greater acceptance of treatments, reduced use of medications and nursing care, a peaceful view of life, reduced stress from highly anthropised environments, control of the spread of respiratory and mental illnesses, recovery from mental fatigue and severe stress (such as violence, mental illnesses, or addictions). In a public health and prevention context, in population health strategies, nature should be considered a fundamental health resource in disease prevention for urban populations worldwide (44).

The commissioning of increasingly significant research and scientific studies is verifying the role of forest therapy in human health. Forest therapy has proven effective in improving immune functions with

beneficial therapeutic effects on the physio-psychological health of urban residents through the lowering of blood pressure, alleviation of stress with reduced salivary cortisol (80) and a significant reduction in depression (81).

Forest therapy is now fully recognised among the many valuable ecosystem services offered by forests. Immersion in the forest produces direct and measurable effects with a broad-spectrum action that affects, among others, the psychological, neurological, cardiocirculatory, and immune spheres (66). Immersion in nature thus fosters a healthy detachment in the peace of green areas (e.g., gardens, orchards, natural parks, reserves, oases, etc.) that fascinate and soothe through colours, shapes, scents, and sounds where each element is in coherence with the others.

Restorativeness and Cognitive Development in Indoor and Outdoor Environments

Restorativeness is evident both indoors and outdoors. Incorporating elements of nature in indoor spaces and the availability of them in well-designed outdoor environments can have significant benefits for individuals' physical and mental health.

In work environments, interaction with green areas, combined with lighting control and sunlight penetration, mitigates the negative impact of work-related stress, reduces the intention to quit, and enhances overall well-being, positively influencing productivity (82). One study suggested that introducing foliage plants into the office environment can lead to improved health and a reduction in discomfort symptoms (–23%), particularly cough (–37%), fatigue (–30%), dry/hoarse throat and dry/itching facial skin (–23%) (83). Residential environments offering areas with abundant and diverse green components stimulate children positively, improving cognitive functions (84) and enhancing performance in tasks requiring attention and cognitive processing. Such conditions can also be achieved through listening to sounds and viewing images depicting natural environments (23,85), such as videos (86) or direct contact (e.g., excursions) (87). Moreover, when it comes to children, a study carried out in Spain (88) showed a beneficial association between exposure to green space and cognitive development, which was partly mediated by buffering against urban environmental pollutants.

Furthermore, research has highlighted that students with a view of nature from their room achieved higher scores in the test administered in the experiment compared with those with a non-natural view (89). These findings are corroborated by other works. A study conducted in Chile showed that higher school greenness was associated with improved individual-level academic outcomes among elementary-aged students, with associations of greater magnitude and strength for students attending public schools (90). Another work (in Brazil) found that greater exposure to green space surrounding schools is associated with higher academic performance, but the associations varied significantly depending on the type of greenness measures used (NDVI, distance from green spaces, and quantity of green spaces) (91). In particular, authors estimated that NDVI was positively associated with school-level academic performance, distance from green areas was negatively associated with academic performance, whereas the number of green areas gave mixed association results.

Three systematic reviews (92–94) confirm the beneficial effects of active or passive exposure to greenness and natural environments on youth development, neurodevelopment and various health outcomes. However, the authors agree that the great heterogeneity in methodologies and the diversity of domains within each outcome make it difficult to draw quantitative conclusions, calling for further longitudinal and mechanistic studies.

The positive effectiveness of interaction with nature seems to be helpful also in cases of immigrants, especially first-generation immigrants from rural backgrounds; by developing feelings of increased identity and integration (in addition to all the benefits described above), they were better able to tolerate the effects of detachment from their country of origin (44,95). Being in natural environments evokes a sense of 'oneness' with nature and the universe, and transcendental experiences have been reported, as well (96). An interest in scientific investigation is emerging regarding human testimonies that recount the relationship between the beneficial effects of care provided by certain plants in the recovery from severe psychophysical traumas (e.g., post-traumatic psychological disorders), with individuals attributing symbolic value to these same plants; this value is linked to the positive effect had in the trauma environment or to the general benefit obtained from contact with plants which are evocative of positive and regenerating memories (73).

When it comes to the elderly, a systematic review reported a moderate relationship between neighbourhood built environment (NBE) and cognition/dementia among older adults, highlighting the need for standardised and long-term NBE measures and high-sensitivity cognitive tests (97). Moreover, a

systematic review with dose-response meta-analysis provided some evidence of a slight inverse association between greenness and dementia at intermediate exposure levels (but not at high levels), underlining however that the available studies might have been affected by the lack of an adequate assessment of potential mediators and/or confounders (98).

The ecosystem services of the Indoor and Outdoor green spaces on the urban environment

Extensive experimental data and technical applications are found in the reviewed literature. However, as of yet, no generally accepted methods have been found that unequivocally establish the vital role that green spaces – in all of their forms – play in providing ecosystem services that benefit urban ecosystems and residential surroundings.

Indoor and outdoor green spaces are key in improving air quality by removing various air pollutants. While long-term exposure to airborne pollutants has been linked to a higher incidence of cardiovascular and respiratory diseases (99,100), neurodegenerative disorders (101) and birth defects (102), short-term exposure to ambient air pollution has been linked to exacerbated asthma that has led to an increase in hospital admissions (103). Exposure to a polluted air environment was also found to be statistically associated with a higher frequency of micronuclei (MN) in children (overall effect size = 1.57 [95% CI 1.39–1.78]), which is in turn potentially associated with several pathological states and a higher risk of developing chronic degenerative diseases (104).

Removing air pollutants also leads to an economic benefit. It has been estimated that the monetary benefit resulting from removing air pollutants such as PM_{10} in Ferrara (Northern Italy) amounts to about 2.12 million euros for 2019 and more than 47.000 euros for O_3 removal (105). In large cities, where air pollution is a frequent problem, careful planning of green spaces is crucial to not aggravate the weight of photochemical contamination (106).

During days of weather stability, with lack of ventilation, intense sunshine and specific humidity conditions (e.g., heat island effect), plants release to the atmosphere biogenic volatile organic compounds (BVOCs) that interact with nitrogen oxides (NO_X) from anthropogenic sources, contributing to the formation of atmospheric ozone. Ozone, peroxyacyl nitrates, aldehyde and ketones, hydrogen peroxide, secondary organic aerosol and particulate material can be formed by the photochemically driven reaction between NO_X, BVOC and anthropogenic VOC (AVOC) (106). Forests that emit isoprene near sources of NO_X pollution (such as metropolitan industrialized areas) can significantly contribute to O_3 formation and peak concentrations observed during the hot summer climate (107).

The creation of volatile organic compounds of anthropogenic origin (AVOC) and the rise in global temperatures are more significant factors contributing to the phenomena of photochemical smog pollution, which cannot be attributed to natural causes. Studies on the plant species best adapted to tolerate this kind of environmental stress may be found in scientific literature; this promotes a reduced atmospheric emission of BVOC (108).

In indoor environments, the main sources of volatile organic compounds (VOCs) come from a variety of sources such as cleaning products, building materials, furniture, cosmetics, deodorants, insecticides, heating devices, cigarette smoke, printers, photocopying machines, glues, paints, adhesives and various solvents. Among them, benzene and formaldehyde are the most dangerous compounds for human health. The associated risks are influenced by the individual's lifestyle and aggravated by the time spent in unhealthy environments; it has been estimated that an urban population typically spends more than 80–90% of its time inside buildings (109). Scientific studies conducted on common dwelling plants have demonstrated the effectiveness of a particular group of species in effectively reducing the concentration of pollutants such as VOCs, cleaning the indoor air and also playing a role in thermal regulation. Research conducted by the National Aeronautics and Space Administration (NASA) in the 1980s, as well as by other researchers (110), demonstrated the potential of plant systems to remove organic compounds (111,112). However, a review pointed out that some experimental conditions might not reflect those of real indoor environments. This may be caused by the dissimilarity between laboratory settings and real environments (e.g., air exchange rates, large volumes, and persistent VOC emissions) (113).

Also, the interaction between plant leaves and airborne microplastics has recently drawn researchers' attention. A recent study demonstrated that even small urban forests (less than 0.2 km^2) has the potential to accumulate more than 2 billion pieces of airborne microplastics per year, also suggesting that canopy leaves could be a long-term sink for this kind of pollutant (114).

Plants, by virtue of their physiology and their role in ecosystem dynamics, improve the quality of soil

and water by helping generate environments suitable for the survival of microorganisms, responsible for the main chemical reactions of decomposition of compounds of anthropic and biological origin (115). Vegetation, based on species-specific ecological adaptations, assumes the function of an environmental sentry capable of providing preliminary complex information on the ecology of a given area and also serves as a bioindicator in environmental monitoring (116).

The presence or absence of peculiar plant species suggests the possibility of being able to identify, in that area, the distribution of certain species of animals, the nature of the soil (alkaline or acidic), the water regime (dry or wet), the orientation of the slope (exposed to the South or the North), the hypertrophy of river waters or whether there are molecules that exceed the limit of tolerance of plants, producing toxicities which might be evident in the appearance of vegetation, the specific composition and the structure of plants (117). The stationary and fixed behaviour of vegetation offers an opportunity to obtain detailed, long-term data remotely, useful for developing models of prediction of water quality in relation to land use (118).

Vegetation has a positive influence on soil chemical and physical characteristics, and understanding the most suitable plant species is essential for effective planning of recovery and restoration of degraded environments. Natural forests have better vegetation characteristics and soil properties than plantation forests, so designing based on models that replicate natural ones would increase their effectiveness (119).

Significant positive interactions between the built environment and acoustic well-being are established in the properties of the vegetation to absorb or spread sound (120,121). Green facades, green walls and the soil on which plants are planted contribute to a dissipative function by destroying sound waves (122). In indoor environments, specific tests have confirmed that plants can absorb a significant amount of acoustic energy, especially in the presence of the soil substrate, which plays a predominant role in acoustical absorption. The barrier effect on the part of vegetation turns out to be a service capable of reducing the noise from point and linear sources (123). Moreover, field studies have demonstrated that thick trees and the regular arrangement of trees reduce the noise from a point source (123). The effects of environmental noise (e.g. noise from road, rail and air traffic and industrial buildings) on non-hearing health fall into the disturbance categories as well as sleep disorders, cardiovascular diseases and cognitive impairment in children; understanding workplace and environmental noise is therefore important for public health.

Moreover, indoor and outdoor green spaces play an important role in the conservation of animal and plant biodiversity, especially in highly urbanised areas. In this context, the habitat generated allows to accommodate animals that characterise the sound landscape of that green area (124). The barrier effect that develops from the presence of outdoor and indoor green areas, such as groves, areas dense with shrubs and trees or sieves, is also related to the search for domestic privacy or generally in open and often overcrowded environments. The presence of outdoor vegetation such as bushes and thick sieves also allows to moderate the microclimate, protecting both vehicles and structures from extreme weather events such as night frosts or excessive sunlight in the summer season.

When it comes to the reforestation of urban areas, researchers suggest the promotion of participatory approaches (citizens, local stakeholders, technicians and other experts) to address the primary needs of the local population concerning the social sphere (105). In order to bring about social change and enhance health outcomes, this type of approach emphasises the significance of forming relationships between investigators and the people for whom the research is primarily intended to be useful (125). They have been conducted on various populations, including young people and vulnerable communities, such as cancer patients (126–132). This approach may bring to an increased awareness and a deeper understanding of the contribution of ecosystem services to collective well-being. In a co-participating decision-making process, social interactions are promoted, strengthening the sense of belonging, participation and preservation. In addition, green spaces improve the quality of urban life by offering equally accessible opportunities for recreational activities and interaction with the natural environment.

This review has some limitations and strengths. The primary limitation of this analysis includes the potential presence of selection bias in the collected data and dependence on the availability and quality of consulted information sources, primarily stemming from the heterogeneity of study protocols, which may make it challenging to compare and synthesise results quantitively. For the same reasons, a systematic study quality assessment was not performed. Additionally, the retrospective nature of the included studies might constrain our understanding of causal relationships between greenness and health. Despite these limitations, this literature review provides a comprehensive

overview of the effects of greenness exposure on human health and the natural and built environment, underlining the importance of considering green as a fundamental element in promoting the psychophysical well-being of individuals and ecosystems, and suggesting the adoption of forest and nature-based therapies and interventions in public health policies and urban practices. Moreover, these results strongly open up new perspectives for nature and biodiversity conservation through the involvement of existing structures such as green areas, forests, nature parks, oases, and sites of conservation interest, and, given the potential for serious and irreversible adverse human health impacts of ecological degradation, closely connect ecosystems and human well-being in a One Health perspective.

Conclusions

In conclusion, several correlations were identified between green exposure and improvements in mental, physical, and overall health and well-being. The studies highlighted the benefits of both outdoor and indoor green spaces, which can positively contribute to individuals' psychological and physical well-being by providing a more relaxing, stimulating, and healthful environment, as well as increasing cognitive abilities, attention, and even stimulating creativity. The presence of vegetation can reduce stress, depression, and anxiety, as well as positively influence blood pressure and heart rate. Moreover, vegetation presence contributes to improving air quality and creating a healthier microclimate in both indoor and outdoor living environments.

Ecosystem services provided by forests and vegetation, such as water cycle regulation (e.g., the biotic pump theory (133)) and air purification, are essential for maintaining a healthy and sustainable urban environment, particularly in mitigating heat waves (134–137).

The presence of green areas in inhabited contexts can foster a sense of overall well-being in communities, promoting social engagement and reducing feelings of isolation by increasing the sense of belonging and stimulating spirituality. This encourages a more active and healthier lifestyle, encouraging people to spend more time outdoors and engage in physical activities. Furthermore, numerous studies have demonstrated that indoor and outdoor greenness has a positive impact on patient healing and recovery in healthcare settings. Practices such as forest therapy and nature contact should be increasingly adopted to enhance people's health and well-being, thanks to the beneficial effects of nature contact. Finally, nature-based solutions are gaining increasing attention in urban design practices, as they offer significant benefits for human health and the ecosystem by harmoniously integrating vegetation into urban spaces to improve quality of life and promote environmental sustainability.

The authors of most studies agree that prospective and/or mechanistic studies will help elucidate unsolved associations and draw quantitative conclusions. Future research should also move beyond the focus on green space presence or proximity, and integrate a deeper analysis of more specific aspects of individual agency that may influence use patterns and perceived psychological and well-being benefits.

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Riassunto

Come il verde esterno ed interno all'abitazione hanno effetto sulla salute umana: una revisione della letteratura

Introduzione. L'analisi delle complesse interazioni tra verde outdoor and indoor e la salute di individui ed ecosistemi è un argomento di attuale e crescente interesse.

Disegno dello studio. Questa revisione della letteratura ha lo scopo di esaminare e riassumere i risultati degli studi condotti per valutare gli effetti dell'esposizione al verde su vari aspetti della salute umana e dell'ambiente naturale.

Metodi. A tal fine, abbiamo condotto una ricerca bibliografica (aprile 2024) utilizzando PubMed, Web of Science, Scopus, Google Scholar e libri specializzati.

Risultati. Le evidenze raccolte dimostrano una correlazione tra l'esposizione al verde outdoor e indoor e il miglioramento della salute mentale, compresa la riduzione dello stress, dell'ansia e della depressione. Il contatto con il verde è anche associato a miglioramenti nella salute fisica, come la riduzione della pressione sanguigna, della frequenza cardiaca e delll'infiammazione, e nelle capacità cognitive, concentrazione e recupero complessivo.

Questi benefici sono riconoscibili sia negli spazi esterni, come parchi urbani, oasi e giardini pubblici, sia in spazi interni, attraverso l'introduzione di piante e elementi che evocano la natura negli ambienti di vita e di lavoro. La presenza di vegetazione in ambienti interni, come uffici, scuole, strutture sanitarie, carceri, ecc. può contribuire a migliorare la qualità degli spazi sociali, promuovere la comunicazione e la collaborazione, e attenuare l'aggressività e le disuguaglianze, aumentando così la soddisfazione dei dipendenti e l'efficienza del lavoro. La combinazione di verde outdoor e indoor e il benessere dell'ambiente abitabile comprende l'esposizione a

una maggiore biodiversità, la mitigazione degli eventi meteorologici estremi, l'assorbimento di inquinanti atmosferici, l'attenuazione del rumore di fondo urbano e l'aumento della privacy. La presenza di vegetazione nelle aree urbane ha un impatto positivo sulla coesione sociale, promuovendo l'interazione interpersonale e – tramite facilitazione dello sviluppo di comunità più coese e inclusive - sostenendo così un senso di appartenenza e identità collettiva.

Conclusioni. In conclusione, questi risultati sottolineano l'importanza di considerare il contatto con il verde come elemento fondamentale per promuovere la salute psicofisica e il benessere degli individui e degli ecosistemi, suggerendo l'adozione di terapie basate sulla natura e interventi nelle politiche di salute pubblica e nelle pratiche di pianificazione urbana.

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