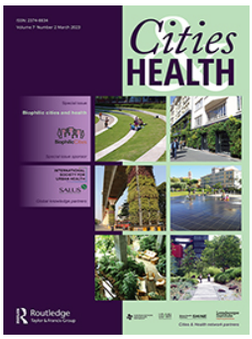

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LEADING EDITORIAL

Biophilic cities and health

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Introduction

Biophilic design emerged at the beginning of the twenty-first century as an integral part of *restorative environmental design*, an approach that seeks to re-establish positive connections between nature and humanity in the built environment by minimizing damage to natural systems and human health (low environmental impact design), and by fostering positive experiences of nature in order to enrich the human mind, body and spirit (biophilic design) (Kellert 2005). Biophilic design is based on the theory that humans have an innate biological affinity for the natural environment (the *biophilia hypothesis* – Wilson 1984, 1993), and is informed by research on the restorative benefits of nature and psycho-evolutionary theories of landscape preference. Kellert identified two basic dimensions of biophilic design: organic (or naturalistic) design involves the use of shapes and forms in buildings and landscapes that directly, indirectly, or symbolically elicit people's inherent affinity for the natural environment, while vernacular (or place-based) design refers to buildings and landscapes that foster an attachment to place by connecting culture, history, and ecology within a geographic context (Kellert 2005, p. 5).

Various frameworks have been developed in order to assist designers with the process of translating biophilia into the built environment by creating spaces that provide a connection to nature in order to enhance mental health and well-being (e.g. Kellert 2008, Browning *et al.* 2014, Kellert and Calabrese 2015). The frameworks are conceived as tools for understanding design opportunities at the building scale, by incorporating nature (e.g. plants, water) in the design of a space, using design features that evoke some aspects of nature – such as ornamentation, use of natural materials, and biomorphic forms – and using spatial configurations characteristic of the natural environment. The frameworks have been widely used to investigate biophilic design in a variety of different settings, including hospitals (Abdelaal and Soebarto 2019), dementia care homes (Peters and Verderber 2021), childcare facilities (Park and Lee 2019), primary schools (Ghaziani *et al.* 2021) and universities (Peters and D'Penna 2020), and have recently been incorporated in some of the main green building rating systems – such as LEED, LBC and WELL[1] – as criteria for assessing the positive effect of building design on the health and well-being of the occupants.

Biophilic cities

The concept of the biophilic city was introduced by Beatley, who suggested that cities '*can be designed and planned to be profoundly more "natureful" and organic, providing opportunities for extensive and deep contact between urban residents and nature*' (Beatley 2008, pp. 277-278), and advocated the need for biophilia-oriented reform of planning and land-use regulatory systems to facilitate this. In his book *Biophilic Cities* he develops his ideas further: '*A biophilic city . . . is even more than simply a biodiverse city: it is a place that learns from nature and emulates natural systems, incorporates natural forms and images into its buildings and cityscapes, and designs and plans with nature*' (Beatley 2011, p. 46). Beatley articulates six expanding scales of the built environment, from buildings, blocks and streets to neighbourhoods, communities and regions. The best biophilic cities are those in which the cascading scales overlap and reinforce biophilic behaviours and lifestyles. He provides four categories of indicator of a biophilic city: (1) biophilic conditions and infrastructure (e.g. percentage of population within 100 metres of a park or greenspace; percentage of city land area in wild or semi-wild nature); (2) biophilic activities (e.g. percentage of population that is active in nature or outdoor clubs; percentage of time residents spend outside); (3) biophilic attitudes and knowledge (e.g. percentage of people that can recognize common species of native flora and fauna; extent to which residents are curious about the natural world around them); and (4) biophilic institutions and governance (e.g. number of city-supported biophilic pilot projects and initiatives; percentage of local budget devoted to nature conservation, recreation, education, and related activities) (Beatley 2011, pp. 47–49).

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In 2011 Beatley launched the Biophilic Cities Project, which sought to apply the ideas, principles and practices of the emerging biophilic design movement to the larger scales of cities and metropolitan areas. The Biophilic Cities Network was launched in 2012 in order to create a global alliance of partner cities, organizations and individuals working collectively in pursuit of the vision of a 'natureful' city (https://www.biophiliccities.org). The partners were invited to join the inaugural Global Conference on Biophilic Cities at the University of Virginia in 2013 in order to define what a biophilic city is, and to foster a common agenda (Söderlund 2019). The first issue of the *Biophilic Cities Journal* was published in 2017, and the Biophilic Cities Network currently comprises 26 cities in North and Central America, Europe, India, Singapore, Australia and New Zealand. Building from the Biophilic Cities Network, the *Handbook of Biophilic City Planning & Design* (Beatley 2016) provides examples of emerging global practice.

Beatley (2016) provides an expansion of his vision of the key qualities and attributes of biophilic cities: they (1) are cities of abundant nature and natural experiences; (2) are biodiverse; (3) are multisensory; (4) are cities of interconnected, integrated natural spaces and features; (5) immerse us in and surround us with nature; (6) are outdoor cities; (7) embrace the blue as well as the green – the marine and aquatic as well as the terrestrial; (8) celebrate the small and the large – from the microscopic to the celestial; (9) are cities where citizens care and are engaged with nature; (10) foster a profound curiosity; (11) care about and nurture other forms of life; (12) care about nature beyond their borders; (13) invest in nature; (14) are inspired by and mimic nature; (15) exhibit and celebrate the forms of nature; and (16) seek an equitable distribution of nature and natural experiences (Beatley 2016, p. 25). A biophilic city is therefore not just a city that has lots of nature within and around it. It is one where nature is engaged with, enjoyed and celebrated, and where the inherent moral worth and value of nature is acknowledged, irrespective of its value to humans. Consistent with a profound ethic of care for nature and other forms of life, biophilic cities also exhibit global leadership in nature conservation.

A complementary approach is found in *Biophilic Urbanism* (Tabb 2020). Biophilic urbanism posits social, sustainable, and economic regeneration of the urban built environment through the development of human communities, and focuses on the ways in which the beneficial qualities of nature can inform planning and design processes through the application of specific design guidelines to varying urban scales, from building elements and interiors to neighbourhoods and communities. It operates from three primary interactions – the impacts of nature on human beings and the built environment, the impacts of human beings and the built environment on nature, and the impacts of the built environment on both nature and human beings – and seeks to encourage positive benefits from these. While biophilic architecture addresses the ways in which a building can help facilitate greater human–nature interactions, biophilic urbanism addresses three other dimensions: the *social dimension* (e.g. mix of uses, creating opportunities for interaction), the *environmental dimension* (e.g. open space, ecological corridors), and the *transportation dimension* (e.g. pedestrianisation, alternative modes of transport) (Tabb 2020, p. 29).

Nature and health

Cross-sectional observational studies have shown evidence of positive associations between exposure to nature, higher levels of physical activity, and lower levels of cardiovascular disease. Increasingly, longitudinal observational studies have started to examine the long-term effects of exposure to nature on depression, anxiety, cognitive function, and chronic disease (Jimenez *et al.* 2021). Spending time in nature, engaging with nature directly and indirectly, and a strong sense of nature connectedness (a psychological/emotional connection with nature) have each been shown to positively impact well-being, both hedonic (e.g. happiness) and eudaimonic (e.g. feeling that life is worthwhile/having meaning in life) (Richardson *et al.* 2021).

Nature may affect human health via multiple pathways. Pathways that have received relatively large amounts of research attention include air quality, physical activity, social cohesion, and stress reduction. The pathways emphasize different aspects of nature – as physical environment, as a setting for individual and social behaviour, and as experience. Since contact with nature involves all these aspects, multiple pathways are likely to be engaged simultaneously and to affect one another (Hartig *et al.* 2014). These four pathways have formed the focus of a number of studies that tested their relative contributions as mediators of the relationship between nature and health. Other frameworks have expanded on this, with one identifying up to 21 plausible pathways while proposing enhanced immune function as the potential central pathway through which nature delivers multiple health benefits (Kuo 2015). Some pathways are direct and potentially involuntary, such as direct physiological restoration from stress, buffering of anthropogenic noise, reduced urban heat island effect, enhanced air quality, airborne phytoncides which kill tumour- and virus-infected cells and negative ions which increase serotonin, ultra violet light which generates vitamin D, and biologically diverse macro- and microbiota that improve the human microbiome. Other pathways are likely to be indirect and occur through facilitating

behavioural and cognitive processes, for example through providing opportunities for physical activity, social interaction, positive emotional and/or spiritual experiences, as well as allowing recovery from cognitive fatigue, and enhancing perceived community cohesion (Cleary *et al.* 2017).

Markevych *et al.* (2017) proposed three general domains of pathways linking nature to positive health outcomes: mitigation (e.g. reducing exposure to environmental stressors such as air pollution, noise, and heat), instoration (e.g. encouraging physical activity and facilitating social cohesion), and restoration (e.g. attention restoration and physiological stress recovery). These domains suggest possibilities for interdisciplinary exchange, since they are not mutually exclusive, and complex interactions and interrelatedness of processes are likely. For example, environmental epidemiologists and environmental psychologists have long studied air quality in terms of air and noise pollution, and an understanding of the respective and interactive effects of those stressors can benefit from a consideration of greenspace as both a mitigating influence and a restorative resource (Markevych *et al.* 2017). Studying pathways in isolation or treating them as orthogonal (i.e. unrelated to one another), and thereby failing to acknowledge that they may work together, can yield potentially misleading conclusions as to their role in the greenspace–health relationship and the relative importance of some pathways over others (Dzhambov *et al.* 2020). For example, the results of an empirical study suggested that physical activity and social cohesion did not mediate the effect of greenspace on mental health when treated as independent variables (mediators), but when tested together with neighbourhood restorative quality the role of these variables was found to be significant. Greener neighbourhoods tended to be perceived as more restorative than other neighbourhoods, and these perceptions related to higher levels of physical activity and social cohesion, which in turn predicted better mental health of the local residents (Dzhambov *et al.* 2018). The pathways between nature and human health are therefore extremely complex. For the sake of simplicity the three domains of Markevych *et al.* (2017) are used here to provide a brief overview of some of the health benefits that humans derive from urban nature.

Mitigation

Greenspace plays a crucial role in promoting human health by providing a wide range of buffering ecosystem services, such as water cleansing, flood mitigation, improving air quality, reducing noise, and preventing heat stress (Zhang *et al.* 2020). The biophilic cities agenda complements the resilient cities agenda, and the former helps to advance the latter (Beatley 2011, Beatley and Newman 2013). Cities worldwide are facing resilience challenges, with climate change causing extreme precipitation events, flooding, heatwaves, and droughts. According to the World Health Organization, worldwide more than 166,000 people died in heatwaves between 1998 and 2017 (Witze 2021). The use of air conditioning to alleviate excessive heat increases carbon dioxide emissions, heat stress, and air pollution, thereby further compromising the health and comfort of urban residents. The enhancement of natural systems within a city can help to make them more resilient, for example by planting trees to provide shade, and installing living walls to cool the microclimate at street level. The composite amount of waterbodies and vegetation in a city – street trees, parks, sports fields, private gardens, green roofs, living walls, etc. – can have a significant effect on the urban heat island phenomenon, while natural wetland systems, restored urban streams and green roofs are better able to absorb stormwater, thereby preventing flooding.

Instoration

Greenspace in cities is considered to be essential for promoting physical activity via active transport (walking or cycling) and leisure (sport or recreation). Greenspace can offer opportunities for nature-based physical activity ('green exercise'), which is positively associated with a lower risk of chronic diseases such as obesity, type II diabetes, and hypertension. A large body of literature shows that green exercise achieves more physical health benefits than equivalent exertion indoors (Zhang *et al.* 2020, Remme *et al.* 2021). There is also a synergistic relationship between physical activity and greenspace on mental health. Regular physical activity improves cognitive function – including memory and attention – and mood and stress resilience, and can have a positive impact on sleep – which is highly protective of mental health – by improving sleep duration, sleep efficiency and sleep onset latency, thus improving mental alertness and performance (Roe and McCay 2021).

Positive interactions in urban greenspace can catalyse social cohesion – the interpersonal dynamics and sense of connection among people – which enhances health and well-being (Jennings and Bakmole 2019). The physical characteristics of greenspace, as well as people's perceptions and use patterns, have been found to directly influence social cohesion. Physical characteristics include the type of vegetation, distance to greenspace, as well as its size, type, layout and structure, facilities, and maintenance. Perceptions of greenness, proximity and safety, as well as the frequency and duration of visits and the activities engaged in, also influence social processes among greenspace users (Wan *et al.* 2021). However, while studies have revealed direct relationships between

greenspace and social cohesion, and between social cohesion and mental well-being, the mediating effect of social cohesion on the pathway from greenspace exposure to mental well-being is still unclear (Zhang *et al.* 2021).

Restoration

Urban dwellers are potentially exposed to particularly high levels of attentional demands and chronic stressors due to particular features of the urban environment, such as noise and light pollution, which may lead to cognitive overload for attention, memory or cognitive control. Urban environments are also characterised by a high occurrence of social stressors, such as transgression of personal space, deprivation/poverty and social fragmentation, and lack of social capital, cohesion and trust that render vulnerable individuals at risk. In addition, pollutants such as heavy metals from traffic exhaust fumes impact negatively on mental health through their effects on the nervous system. As a result, urban environments are associated with an increased risk of mental health disorders such as non-affective psychosis and affective autism spectrum and anxiety disorders (Krabbendam *et al.* 2021, Tonne *et al.* 2021).

A wealth of studies has demonstrated that nature experience is positively associated with psychological well-being. The forms of association include evidence that links nature experience with increased positive affect, decreased mental distress, happiness and subjective well-being, a sense of meaning and purpose in life, improved manageability of life tasks, and positive social interactions, cohesion, and engagement. In addition, nature experience has been shown to positively affect various aspects of cognitive function, memory and attention, impulse inhibition, as well as imagination and creativity. Nature experience has also been associated with improved sleep and reductions in stress, which may entail decreased risk for mental illness. In addition, there is growing evidence that nature experience is associated with a decreased incidence of other disorders, including anxiety disorders, attention deficit and hyperactivity disorder (ADHD) and depression (Bratman *et al.* 2019, Callaghan *et al.* 2020).

The health benefits of urban blue space have received much less attention from researchers than those of urban green space, and the two are often grouped together using umbrella terms such as 'greenspace' (e.g. Collins *et al.* 2020) or 'blue-green space' (e.g. Pouso *et al.* 2021). While separating the health effects of green and blue spaces is difficult since they often co-exist (e.g. a lake in a park), it has been argued that blue spaces provide different human experiences from those offered by green space, and may therefore impact health outcomes in different ways. Urban blue spaces offer different kinds of recreational opportunities, they attract different kinds of wildlife, and they are sensed in different ways – for example, running water has sonic qualities which can create relaxing soundscapes (Haeffner *et al.* 2017). Empirical evidence suggests that urban blue space increases physical activity, enhances restoration, and mitigates environmental stressors such as heat. Blue space may also have a beneficial effect on social interaction, but the evidence for this pathway is mixed (Georgiou *et al.* 2021). A meta-analysis of publications on the health impacts of urban blue spaces found small but statistically significant effects on obesity, self-rated general health, and mental health and well-being, as well as reduced risk of premature all-cause mortality (Smith *et al.* 2021).

The articles in this issue

The articles in this special issue arose from a conference on 'Activating Biophilic Cities' held at the University of Greenwich, London, in 2018 and a subsequent call for papers. The conference aimed to share best practice in biophilic design, and to kick-start the pace of change towards providing places and spaces that improve the quality of life in our cities. The articles address different scales of the biophilic city – from city-wide mapping of biophilic elements down to the optimal design of workplaces and aged care facilities – using approaches and methodologies that can be translated to cities around the world.

Pedersen Zari presents a framework for analysing biophilic urban elements which she then uses to map Wellington, New Zealand, which joined the Biophilic Cities Network in 2013. Partly in order to test the validity of the claim that Wellington is biophilic, she set out to use GIS mapping techniques to determine specific areas, sites, and buildings that could be identified as being either sites of nature in the city, places where nature activities are possible, or designed biophilic places or spaces. Building on Beatley's writings on the aspects of cities deemed important in creating relationships between people and nature, as well as Kellert's biophilic design framework (Kellert 2008) and the *14 Patterns of Biophilic Design* (Browning *et al.* 2014), the biophilic urbanism framework identifies 30 unique characteristics of biophilic cities. The mapping of these elements revealed clear clusters within Wellington. Gathering spatial data related to demographics and how people move about the city, and overlaying these onto maps showing existing biophilic elements, would facilitate strategic decisions about where to include additional biophilic elements and how to connect them together through dedicated pedestrian zones or green corridors.

The key determinants of a person's health are thought to be lifestyle, community, local economy,

activities, and the built and natural environment (Barton and Grant 2006). In a highly relevant paper we previously published, Heath *et al.* (2022) combine the four psychological elements identified by McMillan and Chavis (1986) as being necessary for a sense of community and belonging to exist – membership, influence, fulfilment of needs, and shared emotional connections – with Kellert's socio-psychological approach to biophilic design (Kellert and Calabrese 2015) in order to explore how designing for community can enhance a sense of space, place and connectivity. The resulting seven 'Biophilic Features for Enhancing a Sense of Community' are translated into spatial considerations for workplace design: (1) diversity of spaces; (2) zoning spaces; (3) soft boundaries; (4) collision spaces; (5) growing spaces; (6) sensory spaces; and (7) triangulation. These features can equally be applied to other sectors, such as hospitality or urban planning.

The importance of co-design processes in urban greenspace planning and governance is increasingly recognised. Co-design is a creative approach that engages stakeholders in order to bring together different real life experiences, perspectives and skills to address a specific problem, and thus has a huge potential for raising their awareness and increasing their sense of place. A well-planned co-design process and engagement strategy supports inclusive participation and social learning through enabling knowledge, dialogue, learning, and equity in urban planning processes (Basnou *et al.* 2020). An example of a co-design process is the urban living lab, which can be defined as '*a local place for innovative solutions that aims to solve urban challenges and contribute to long-term sustainability by actively and openly co-constructing solutions with citizens and other stakeholders*' (Chronéer *et al.* 2019, p. 60). In this issue Barau *et al.* explore the potential for urban living labs as a method for co-designing urban ecosystem restoration. The MR CITY Lab (Millennials and Resilience: Cities, Innovation and Transformation of Youths) at Bayero University in Kano, Nigeria, was a design-thinking initiative where students, academics, and forestry experts co-designed protocols for reintroducing native trees to the city. The ideation lab was then translated into a field-based community-engaged urban greening project.

Another example of a co-design process is provided in the paper by Giusti, Wang and Marriott. Participants at a workshop were presented with a scenario for Connecting Land, a hypothetical community of 1000 people that is able to ecologically sustain its population, nurture children's connection with nature, and provide quality nature experiences for the whole population. After brainstorming the salient aspects that would constitute everyday life in Connecting Land, participants were then asked to identify the essential policy actions that would need to be put in place in order to achieve it. The visions which emerged from this exercise were overlapping and complementary, and suggest a variety of psychological, physical, cultural, and environmental attributes that interplay with each other. Children's education was seen to be a top priority, alongside rewilding the landscape and the creation of space that is shared and cared for by the community and in which children can move freely. The policy actions emerging from the workshop suggest that achieving Connecting Land would require integrated policies that simultaneously address children's experience-based education, the elimination of physical barriers to nature access, and legal actions to establish the rights of natural elements.

Beatley (2016) suggests that an easy first step in developing biophilic cities is to restore and enhance the nature already present. Residential gardens offer an opportunity to increase biodiversity by making small adaptions to turn them into a habitat for wildlife yet, as Webb and Moxon discuss in their paper, this will require supporting interventions to influence individual behaviour. A range of personal and social factors influence pro-environmental behaviour, including age, gender, religion, social class, knowledge, control, a connection to nature, childhood experience, and political and world view, so in order to influence behaviour, it is important to specify the behaviour in question as closely as possible. Webb and Moxon provide a methodology for using the Behaviour Change Wheel model (Michie *et al.* 2011) in order to understand the capability, opportunity and motivational factors influencing urban rewilding behaviour, and to identify the necessary intervention functions (e.g. education, enablement, training) and policy categories (e.g. guidelines, fiscal measures, legislation) that would promote such behaviour.

The Jerusalem Railway Park (or Train Track Park), which follows part of the route of the disused Jerusalem–Jaffa railway, is seen as a symbol of coexistence in a divided city, since it passes through Jewish and Arab neighbourhoods and is used by residents of both. The park was created after local resident groups mobilized to resist the creation of a four-lane highway, advocating for urban greenspace instead. Planned and constructed with broad community involvement to ensure that the needs of local residents were met, the result is a 7 kilometre long park with walking and biking trails and exercise equipment. Using in-depth qualitative observation, face-to-face interviews, surveys and documentary research, Greenshtein *et al.* assess the health benefits of the park, particularly with regard to active living among people aged 55 and older, and use the framework of Sallis *et al.* (2006) which identifies potential environmental and policy influences on four domains of active living –

recreation, transport, occupation, and household activities – to contextualize their findings.

Research in environmental cognition suggests that the real world is too complex to be processed completely, so people create their own version of reality by selecting only those environmental features that produce affective responses. In their paper, Mirza and Byrd argue that viewing an urban landscape on a daily basis makes some features stand out more than others, depending on environmental and personal factors. Preferences held for these prominent perceptual features are proposed to be the determinants of preference for the overall landscape. The Active Perception Technique aims to capture these features and to explore the relationship between their visual quality values and the overall view by using windowscapes viewed on a daily basis. In a trial performed in Auckland, New Zealand, participants were asked to sketch from memory what they could recall of the view from their window, express their preference for each feature on the sketch using a five-point Likert scale, and provide a photograph of the view. Natural features were preferred over built ones, with large bodies of water and the sky being the most preferred features, and park land being the most preferred type of greenery, followed by garden trees. Results obtained from Active Perception Technique studies such as this have a clear potential to be useful for policy makers and planners to enhance the visual quality of built environments and to provide more likeable and liveable cities.

Public streets are one of the areas where there is the greatest potential to provide city dwellers with increased access to nature. Ede and Morley present Transport for London's 'Healthy Streets Approach', a framework which integrates health into planning and design decisions and promotes a collaborative approach between transport specialists and designers. While the framework focuses primarily on promoting active travel in order to reduce congestion and improve air quality, Ede and Morley consider how it might be adapted to promote the biophilic cities movement by encompassing other health and well-being objectives, including mental health.

In their paper Miller and Osborne Burton call for changes in the way we plan, design and build aged care facilities, proposing a new approach grounded in biophilic design. Since living in aged care can be dull, encouraging innovative design practice that maximizes interactions with nature is one practical strategy that could greatly enhance the life of the residents, their visitors and the care staff. Using the framework of the *14 Patterns of Biophilic Design* (Browning *et al.* 2014) as a guide, the authors use three Australian case studies to illustrate how aged care design practice can be biophilic, although the phrase is rarely used in architectural design for aged care discourse.

Biophilic cities in the light of COVID-19

By promoting physical exercise, enhancing mental health and reducing long-term chronic stress, biophilic cities increase the resilience of individuals and communities. Arguably nothing has put our resilience more to the test than the COVID-19 pandemic. With partial or total lockdowns aimed at drastically reducing the spread of the virus by restricting people's mobility, the pandemic has provided a unique opportunity to examine changes in urban nature use during a period of personal and community stress, to gather information about people's reasons for engaging with nature, and to learn lessons for the future. The pandemic can therefore be seen as a 'global natural experiment' in human–nature interactions that can provide unprecedented mechanistic insights into the complex processes and dynamics of these interactions and into possible strategies to manage them to best effect (Soga *et al.* 2021b, Tomasso *et al.* 2021).

Some studies of the impact of the pandemic on greenspace visiting rates have reported an overall increase compared to pre-pandemic times, on both a global scale (e.g. Ugolini *et al.* 2020, Geng *et al.* 2021) as well as within specific cities (e.g. Venter *et al.* 2020, MacKinnon *et al.* 2022), which could suggest a widespread conscious desire to seek interactions with nature during a period of stress – a manifestation of 'urgent biophilia'. In contrast to the biophilia hypothesis, which suggests that our innate affinity to nature is mostly subconscious, urgent biophilia suggests that humans consciously seek out contact with nature to strengthen their resilience during a crisis or disaster (Tidball 2012). Urban greenspace provided a place of respite from the stress inflicted by the pandemic – a place to relax and take exercise, or to engage with the natural world and, as lockdown restrictions eased, a place to socialise.

A number of studies have investigated the effect of urban greenspace on mental health during the pandemic (e.g. Dzhambov *et al.* 2021, Lõhmus *et al.* 2021, Reid *et al.* 2022). For example, a cross-sectional study of the association between greenspace and four metrics of mental health – COVID-19-related worries, anxiety, depression, and a weighted composite score generated from all three measures – conducted in the United States during the first six months of the pandemic, at a time when the majority of those sampled were restricted by social distancing precautions, found significant protective effects of greenspace on both depression and composite mental health scores across the entire cohort, while exploratory analyses suggested that certain age groups benefited more than others

(Wortzel *et al.* 2021). A study conducted in Tokyo, Japan, found that the frequency of greenspace use and the existence of green window views from within the home was associated with increased levels of self-esteem, life satisfaction, and subjective happiness, and decreased levels of depression, anxiety, and loneliness (Soga *et al.* 2021a). An international survey conducted during the first wave of the pandemic found that greater lockdown severity was associated with a greater likelihood of exhibiting symptoms of mental health disorders, with people who had no access to public greenspace more likely to show symptoms of anxiety and depression than people who had partial access or no restrictions at all. Under the strictest lockdown, individuals with private greenspace or with window views of nature experienced fewer symptoms of depression and anxiety and more positive mood compared with those with urban views or no views at all. The study also found that psychological resilience, age and gender were important factors predicting the likelihood of showing symptoms of depression and/or anxiety (Pouso *et al.* 2021).

The pandemic also highlighted the disparity in distribution in terms of the quality, functionality and location of greenspace in urban areas, which meant that in many cases communities with higher ethnic diversity, lower income and poorer health suffered from insufficient access (Mell and Whitten 2021), thereby exacerbating health inequity. For example, Pipitone and Jović (2021) found that the pandemic has widened existing socio-spatial disparities in New York. The higher the medium income per household in a neighbourhood, the higher was the reported use of urban greenspace before and during the pandemic. A key finding of the study was the importance of a sense of belonging. The main factors contributing to a sense of belonging were access/proximity to greenspace, being a long-time resident in the area, growing up near a park, having access to well-maintained greenspace, love of nature, feeling safe, and opportunities to volunteer. The extent to which people felt they belonged to their urban greenspace correlated strongly with the socio-economic characteristics of their neighbourhood, with the lowest income neighbourhoods registering the lowest sense of belonging. Sense of belonging can be regarded as both a cause and effect of socio-spatial inequity. A lower sense of belonging is related to lack of access or poor access to greenspace, which in turn leads to a perception of greenspace as an amenity rather than a necessity, which in turn leads to a lower need and/or sense of entitlement to advocate for access to greenspace, thus revealing a vicious cycle of inequity that needs to be broken (Pipitone and Jović 2021).

The process of making cities more biophilic must take into account the potential implications for the environmental justice of local communities. While biophilic cities strive for abundant, accessible nature, and aim to improve the equity in distribution of nature by targeting greening efforts in deprived neighbourhoods, this can have the unintended consequence of gentrification (Panlasigui *et al.* 2021). The improvement or construction of new environmental amenities such as parks, entwined with political and economic agendas, may ultimately socially and physically exclude or even displace long-term underprivileged residents. Although some argue that gentrification should reduce social, physical, and health inequalities due to social mixing and improvements in access to cultural and environmental resources and other services among the lower-income residents, research shows that by some measures, residential socio-economic segregation increases in neighbourhoods experiencing gentrification (Cole *et al.* 2021, Jelks *et al.* 2021). Gentrification can lead to feelings of socio-cultural erasure and decreased social cohesion among the underprivileged residents, which can be linked to a wide range of health outcomes, including obesity, cardiovascular diseases, asthma, chronic stress and depression (Anguelovski *et al.* 2020). By leading to worse outcomes for underprivileged groups, gentrification may in fact exacerbate existing patterns of health inequity. How mental and physical health is affected by living in gentrifying neighbourhoods therefore complicates traditional understandings of the health effects of neighbourhood improvements intended to make them greener, more liveable, and more walkable (Cole *et al.* 2021, Jelks *et al.* 2021).

Healthy biophilic cities: a research agenda

Simply by making our cities more 'natureful' does not mean that human health and well-being improvements will necessarily follow. For example, determining which aspects of nature are relevant to mental health is a key research frontier. More information is needed with respect to the benefits afforded by different types of urban nature (e.g. green space, blue space, biodiversity); the kinds of benefits realized with visits of differing duration or involving different activities; how benefits realized with individual visits or with episodes of viewing nature might aggregate over time; and how these factors may change throughout a life course. All these missing links weaken the potential for the evidence of the health benefits of urban nature to have an impact on decision makers and to facilitate the creation of urban greenspace policies that could have a positive benefit on health and thereby help to narrow health inequities (Markevych *et al.* 2017, Jimenez *et al.* 2021).

Demographic and socio-economic factors – such as age, gender, race, income, and education – all play a significant role in modifying the impact of the natural environment on mental health outcomes,

although there are inconsistencies in the research findings, so one cannot assume uniform benefits across particular sub-groups. The mental health benefits of urban nature have largely been conceptualised from a western perspective, and more research is needed on how these benefits are impacted by different cultural values, traditions and perceptions. Advancing this research in rapidly urbanising low- and middle-income countries is particularly important (Roe and McCay 2021).

Urban nature spans a continuum of different levels of human intervention, design and management. Regardless of the level of human influence, what is (or isn't) considered to be urban nature will depend on how people perceive it to be 'natural', with some people valuing elements of urban nature that others disregard as being inferior or even inauthentic. The degree to which such settings are perceived as 'urban nature' may depend on people's personal experiences, as well as the prevailing cultural representations of nature that they are regularly exposed to. Consideration of such personal and cultural conceptions of nature is therefore critical when seeking to define and understand urban nature and the everyday exposures of urban residents (Cleary *et al.* 2017). For example, more research is needed on the mental health and well-being benefits provided by building-integrated vegetation, such as green roofs and living walls. While these design features have been well-studied in terms of their environmental benefits, to date there have been very few studies of their potential for providing restorative experiences (e.g. Elsadek *et al.* 2019, Mesimäki *et al.* 2019). The psychological benefits may be influenced by the plant selection and design, but also by people's views on what nature in cities should be like, which will shape whether they consider building-integrated vegetation to be restorative or not (Williams *et al.* 2019).

A greater understanding is needed of the specific pathways through which immersion in nature benefits mental health and well-being. For example, experiences of awe have been proposed as one such pathway (Kuo 2015). Awe is a positive emotion, distinct from feelings of joy or beauty, which arises in encounters that are vast or transcendent, and engages five processes that all benefit well-being – shifts in neurophysiology, a diminished focus on the self, enhanced prosociality, greater social integration, and a heightened sense of meaning. Awe in nature reduces rumination and stress, and elevates well-being (Monroy and Keltner 2022). Like all emotions, awe is subjective. How can we design awe into urban nature? What would it look like, or sound like?

Studies on the restorative value of urban nature tend to focus on the visuo-spatial experience, using stimuli such as photographs, videos, and slideshows, but environments are not experienced through vision alone. There is growing interest in and a call for research on the non-visual aspects of urban nature, including sound, smell, and touch (Ratcliffe 2021). Smell can have profound effects on our mood, behaviour and cognition, yet there are very few studies on the role of smell in delivering health and well-being benefits of nature experiences, while research on the role of non-animal nature touch, such as the feeling of grass under one's feet, is a significant gap in the literature (Franco *et al.* 2017). Since biophilic cities are multi-sensory and promote active engagement with nature rather than just passive exposure to it, immersive experiences of spaces need to be studied in order to obtain more accurate insight on the restorative effects of nature.

Also poorly understood is how and to what degree different spatial configurations of nature promote mental health in a community (e.g. whether one large park is better for serving restoration needs than many smaller green spaces) and if this varies by context, across population groups, and with different greenspace designs (Markevych *et al.* 2017). Interventions that aim to improve health and well-being through simply increasing the provision of and/or access to urban nature, in isolation from targeted interventions to connect and engage people with the nature space, may not deliver on the intended health outcomes. The connection and relationship occurring between nature and the person experiencing it therefore needs to be understood and facilitated within the design and creation of urban nature in order for it to deliver on its reported multiple benefits (Cleary *et al.* 2017).

Although many studies support the notion that social cohesion and social capital are determinants of psychological well-being, more research is needed to fully understand the role of social cohesion and its link between greenspace and health. To date few studies have explored the link between social cohesion and factors such as different types and quality of greenspace. As the level of social cohesion can exhibit spatial and temporal variation, some scholars recommend the use of longitudinal study designs and research which tries to understand the role of active versus passive uses of greenspace (Jennings and Bakmole 2019).

Much of the research on urban nature and human health has focused on the presence, size, accessibility or proximity of greenspace. While these metrics can serve as important indicators for urban health planning goals, they do not enable a clear understanding of how physical and mental health is influenced by the ecological characteristics of greenspace. Indeed, the role in human health and well-being played by biodiversity – the variety of species, the genetic variation within those species, and the variety of ecosystems in which the species reside – remains largely unexplored.

Biodiversity may have both direct and indirect impacts on the potential for greenspace to benefit health. For example, high plant diversity may result in high structural and functional variation which determines the potential for greenspace to mitigate air pollution, while biodiverse greenspace may host a high diversity of environmental microbiota which may mediate biodiversity effects on human health through the immune system (Aerts *et al.* 2018). The relatively small number of studies, which have primarily focused on plants and birds, combined with methodological heterogeneity and a wide diversity of metrics used for both biodiversity and health and well-being, mean that it is difficult to generalise from the findings, while the lack of controlled case studies or longitudinal analyses leaves a gap in knowledge surrounding causality and the long-term consequences of exposure to biodiverse environments (Marselle *et al.* 2019, Houlden *et al.* 2021). A key research gap is to understand – and evidence – the specific causal pathways through which biodiversity affects human health, and to understand how the type of experience of biodiversity – direct or indirect, intentional or incidental – and the frequency and duration of exposure to it may influence health outcomes and the mediating pathways. Moderating factors relating to the sociocultural context and to individual characteristics have all been found to influence nature–health relationships, and are likely to moderate biodiversity–health pathways too (Marselle *et al.* 2021a, 2021b).

The relative benefits of encouraging more biodiversity in our cities need to be weighed against the potential disbenefits, such as the risk of transmission of zoonotic and vector-borne diseases. Cities provide ample opportunities for peridomestic scavengers (Figure 1), and since most of the emerging infectious diseases in humans are zoonotic, cities crowded with both animals and people are likely hotspots for future disease emergence (Lindahl and Magnusson 2020). While proponents of the 'dilution theory' posit that increased biodiversity can reduce the abundance of a particular parasite species per host and thus reduce the risk of infectious diseases caused by that parasite, supporters of the 'amplification hypothesis' maintain that the opposite is the case, and this argument has yet to be resolved (Rohr *et al.* 2020).

In urban areas across the globe the rapid rise of non-communicable diseases, such as auto-immune and inflammatory diseases, has been linked to reduced exposure to biodiversity. One hypothesis for this rise is that urban children do not have sufficient opportunities to interact with microbiota from natural ecosystems, which are important for training the immune system. Microbiome rewilding – the ecological restoration of microbiota and their habitat in urban greenspace – therefore has the potential to alleviate the burden of such diseases by increasing opportunities for biodiversity exposure. Greater contact with environmental microbiota may also be protective against infectious diseases, since they supplement our own protective microbiota, participate in immune signalling, and help to build adaptive immunity (Mills *et al.* 2019). An exciting new area of research is 'microbiome-inspired green infrastructure' – multifunctional greenspace that is designed and manipulated to enhance public health via health-inducing microbial interactions. Urban habitats that improve immunoregulation could be created by explicitly choosing plant species which interact in order to influence the composition of the microbiota, and by inoculating

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Figure 1. Biophilic cities: are some types of nature more welcome than others?

landscape materials to optimise human-microbial interactions. For microbiome-inspired green infrastructure to progress from theory to practice it will require a better understanding of environmental microbiome dynamics, such as the functional relationships between microbiota and vegetation, spatiotemporal and compositional dynamics, and the mechanisms and pathways that facilitate human–microbial exchange and the associated benefits (Robinson *et al.* 2018, Watkins *et al.* 2020).

Retrofitting our cities to be more biophilic offers opportunities to mitigate the effects of climate change. With heatwaves becoming hotter and more frequent across the world, there is an urgent need to understand the most appropriate way to reduce the urban heat island effect. The heat-related health outcome in cities is the aggregated impact of thermal, social, economic and demographic risk factors. Lower socio-economic groups are more likely to live in neighbourhoods with higher building density and limited vegetation cover, and consequently have a higher exposure to heat stress (Santamouris 2020). While in general the size of greenspace is positively correlated with the cooling intensity, this relationship is not linear, and a number of other factors play a role, including its type (tree-covered or grass-covered), shape, connectivity, and complexity (composition and configuration), the greenness of the vegetation, as well as seasonal, diurnal, latitudinal and climatic differences. The size and shape of water bodies affect their cooling effect, and the wind direction and specific landscape pattern around a water body, as well as its latitude, also play a significant role in this. In particular more research is needed to quantify the threshold-size in order to define the minimum amount of blue-green space needed in order to achieve the optimal cooling effect in a specific location (Yu *et al.* 2020).

Increasingly, the notion of urban nature is at the forefront of the urban design and planning conversation in terms of the provision of 'nature-based solutions' to a variety of challenges, in particular those posed by climate change and biodiversity loss. However, focus also needs to be directed towards nature-based solutions that foster public health, not least because of the nexus between climate, biodiversity, and public health. Climate change impacts both biodiversity and health, and functioning ecosystems are needed in order to mitigate its effects, while the value that nature provides for human health offers increased opportunities for the biodiversity agenda. Integrated policies that address these linkages would help to frame holistic solutions to build better symbiotic relations between humans and nature that will have positive impacts on both health and resilience.

Note

1. Leadership for Energy and Environmental Design (LEED), Living Building Challenge (LBC), WELL Building Standard (WELL).

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We are grateful to all of the reviewers whose work supported the authors in developing and improving their papers. And, of course, we thank all the authors who submitted papers to this issue, both those that were accepted, and those that following review we were unable to publish. Finally, we wish to acknowledge you, the reader. We hope that you find material here to stimulate new thoughts (and hopefully actions) in the pursuit of better support for population and planetary well-being through the way we incorporate nature as we plan, design, and govern our towns and cities.

We also acknowledge the support of our special issue partner, who has helped support the call for papers, the review of submissions and the dissemination of this work.

A few words from our special issue partner

Biophilic Cities is a global network of cities, organizations and individuals based in the School of Architecture at the University of Virginia, in the U.S. Our vision is one of cities that place nature at the centre for their design and planning and that recognize nature as an absolutely essential element in achieving a healthy and flourishing life. Currently there are twenty-six cities participating in the network as 'partner cities', as well as hundreds of organizations and thousands of individuals. The network works to collect and share good practice (through books, films, webinars and other network-sponsored events) and to facilitate collaboration and sharing between cities as they work to become more biophilic and natureful. We are honored to partner with Cities & Health on this special issue and to have been part of the Activating Biophilic Cities conference at the University of Greenwich that gave rise to it. The vision and practice of Biophilic Cities we believe will be one of the most important pathways to achieving urban health.

More about the network can be found here: www.biophiliccities.org

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