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REVIEW

Biophilic design in architecture and its contributions to health, well-being, and sustainability: A critical review

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Abstract In the last ten years, 'nature' and biophilic design have received widespread attention in architecture, especially in response to growing environmental challenges. However, open questions and controversies remain regarding conceptualizing and addressing 'nature' in practice and research. This study conducts a literature review to discuss biophilic design as a theoretical framework to interpret 'nature' in architecture. The following questions are answered: (1) How has the concept of biophilic design emerged, and how can it be defined? (2) In what ways can biophilic design contribute to the goals of sustainable architecture? (3) What are the key design strategies in biophilic design? This review identifies and compares the key frameworks of biophilic design and explains their major elements. We then analyse the benefits (e.g., enhance health, well-being, productivity, biodiversity, and circularity) of biophilic design in achieving sustainability, as framed through the UN Sustainable Development Goals. The results indicate that biophilic design is more complex and richer than the mere application of vegetation in buildings; it broadens the variety through encompassing different types of nature from physical, sensory, metaphorical, morphological, material to spiritual. Moreover, knowledge gaps are identified to motivate future research and critical reflections on biophilic design practices.

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1. Introduction

In the last decade, a growing interest in rediscovering 'nature' has emerged, driven by a fascination and desire for 'nature' and the ambitions towards improving health, well-being, circularity, and resilience. However, 'nature' is a vague, elusive, and contested term, and the effectiveness of 'nature' in architecture often arouses debates and criticisms. One crucial question is how to conceptualise 'nature' as a notion, as 'nature itself is not nature: it is a concept, a norm, a recollection, a utopia, an alternative plan' (Beck, 1999, p. 21). It is also worth considering how to critically address literal greening as a marketing tool with limited impacts on tackling social, economic, and environmental challenges.

1.1. A brief historical overview of 'nature' in architecture

The interrelation of 'nature' and architecture has a long history, as exemplified through a few selected examples (Fig. 1). The legendary Hanging Garden of Babylon is believed to have been a magnificent construction in classical antiquity that was adjacent to the water source and filled with a rich variety of trees, shrubs, and grapevines in terraced gardens. In the oldest extant book in western architectural theory *Ten Books on Architecture*, Roman architect Vitruvius explained the response to climate in domestic buildings and the dependence on water. Furthermore, designing with natural sceneries is popular in wealthy families' suburban villas, such as the Italian Renaissance gardens designed in the Villa di Castello and the picturesque English landscape gardens arranged in the surrounding of the buildings in Stourhead. Landscape architecture was further developed in the 19th century. Andrew Jackson Downing popularised the use of front porches to link houses and nature in private dwellings. Moreover, architects acquired experience from Gothic architecture and suggested applying natural forms as rational structures, which can be seen in Eugène Viollet-le-Duc's decorative cast iron works, Victor Horta's Hôtel Tassel, Antoni Gaudí's Casa Batllo, and many others.

In modern architecture, architects explore living with nature through a broader range of approaches. For instance, Leberecht Migge proposed the installation of edible gardens in social housing. Apartments with private gardens were included in Le Corbusier's conceptual project, Immeubles-villas. Additionally, many prominent modern architectural

projects reflect co-existence with nature. Frank Lloyd Wright's Fallingwater embraces nature by placing the building, especially the horizontally extended cantilevered terraces, in the midst of nature. Farnsworth House by Ludwig Mies van der Rohe establishes a connection with the external natural environment through the use of glass walls and light structural supports. Later, in the 1960s, the increasing awareness of the impact of contemporary life on the environment stimulated an environmental awakening (Tabb and Deviren, 2013). Landscape architect and town planner Ian McHarg (1969) suggested an ecological perspective that incorporates the analysis of land, climate, and water into urban planning. The 1960s were also a radical period in architecture. Avant-garde architects such as Mario Bellini, Alberto Rosselli, Ugo La Pietra, Archizoom, Superstudio, 9999, and others reflected on the destructive impacts of modern construction on the natural environment in their projects. Although most were visual and experimental works, environmental awareness triggered a shift in the value of the relationship between humans and nature.

1.2. Environmental awareness and emergent sustainable architecture

The interest in and fascination with 'nature' must be seen in relation to human-induced environmental crises and emerging environmental movements. In the 1980s and 1990s, 'nature' was explored and associated with a range of environmental issues of the era. New concerns such as climate change, ozone depletion, and loss of biodiversity emerged, and solutions to these issues, came to be characterised within the call for sustainable development (Leach et al., 2010). The concept of sustainable development was brought to public attention in 1987 through the Brundtland Report (UN, 1987) and was further elaborated through the Agenda 21 (UN, 1992) and the 17 Sustainable Development Goals (SDGs) (UN, 2015). However, climate crises, biodiversity loss, air pollution and many other issues remain urgent challenges today. To address a variety of challenges in sustainable manners, the European Commission (2015) launched 'nature-based solutions' with a series of actions that are 'inspired by, supported by or copied from nature' to deploy various natural features and complex system processes in a resource-efficient way to diverse urban areas. Available technologies were examined, and the benefits of these strategies were investigated through the assessment of thermal performance, air quality, acoustic insulation and noise reduction, urban stormwater management, and biodiversity (Perez and Perini, 2018; Somarakis et al., 2019). Nonetheless, the current focus is primarily on the urban scale. Research on understanding the impact of nature-based design in architecture is still limited.

The building sector plays an essential role in sustainable development and is responsible for nearly 40% of energy consumption and energy-related carbon dioxide emissions (IEA, 2017). Buildings also have a significant impact on human health and well-being, as we spend approximately 90% of our time indoors (European Commission, 2003; Roberts, 2016). Reconnecting with 'nature' has been recognised as one of the most urgent challenges in contemporary urban architecture (Beatley, 2017; Ives et al., 2018). Especially during the COVID-19 lockdown, most of the urban dwellers had minimal access to gardens, parks, or the countryside. In this context, the integration of 'nature' into buildings has been increasingly celebrated recently. In both academic research and architectural practice, there is growing interest in strengthening the effects of contact with 'nature' while reducing humans' impact on the natural environment. Within the broad field of sustainable

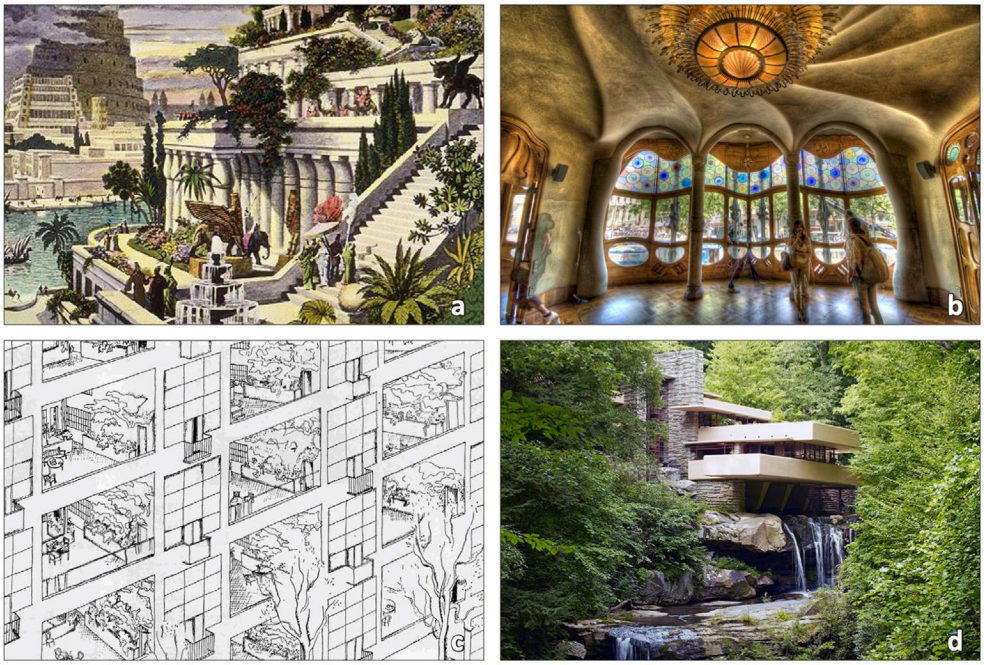

Fig. 1 Examples of the integration of plants, water or analogous natural forms in architecture [Source: (a) Hanging Garden of Babylon (b) Antoni Gaudí's Casa Batllo; (c) Le Corbusier's Immeubles-villas; (d) Frank Lloyd Wright's Fallingwater]

architecture, we witness the tendency of increasing 'greening' of architecture through elements such as green facades, green roofs, and vertical gardens. In some cases, easy promotional language conceals the lack of real improvements or effectiveness (Leach et al., 2010). Moreover, the notion of 'nature' is rather elusive and can be interpreted in many ways: as essential materials for human survival; as sources of inspiration for architectural design; or as a mere romantic idea. In this article, the concept of biophilic design is discussed as one approach to conceptualise and understand 'nature' in architectural design.

1.3. From the theory of biophilia to biophilic design

The term *biophilia* was coined by social psychologist Erich Fromm (1964) to describe the 'love of life' that explained two fundamental tendencies of living organisms: sustaining life from death threats and the positive integration with each other. Biophilia theory did not receive wider recognition until 20 years after it was first proposed. The biologist and naturalist Edward Wilson (1984, p. 1) defined 'biophilia' as 'the innate tendency to focus on life and lifelike processes'. Wilson (1993) further raised 'the biophilia hypothesis' to interpret that the emotional connection with 'life' was conserved after humankind migrated from the primitive natural environment into the artificial new environment. He emphasised that biophilia is 'the innately emotional affiliation of human beings to other living organisms', in which the 'innate tendency' represents the characteristics of 'hereditary'; meanwhile, as a 'learning rule', it provides an enlightening perspective with which to understand nature (Wilson, 1993, p. 31). The former point is supported by psycho-evolutionary theory, which argues that some emotional reactions are rooted in human evolutionary history and developed to adaptive responses to modern society (Ulrich, 1983). The evolutionary dependence on 'nature' was also expounded by social ecologist Stephen Kellert (1993) by identifying nine values of biophilia: 'utilitarian, naturalistic, scientific, aesthetic, symbolic, humanistic, moralistic, dominionistic, and negativistic'. The latter point might be a deliberate 'softening' of 'innate', which prevents biophilia from being restricted to the significance in evolutionary psychology (Joye and de Block, 2011). For instance, the loss of biodiversity is the most obvious example that illustrates the ways in which biophilic and environmental issues are closely related (Wilson, 1993, p. 35). Furthermore, Kellert (2008a, p.462) pointed to biophilia as 'the inherent human inclination to affiliate with natural systems and processes, most particularly life and life-like (e.g. ecosystems) features of the nonhuman environment'. Since the 1990s, the concerns of the biophilia theory have shifted from its initial focus on life or living organisms to exploring the relationship between humans and the natural environment.

At the beginning of the 21st century, the notion of biophilia was developed and adapted within the architectural domain, drawing attention to the emotional aspect of humans' needs for interactions with the natural environment in the building environment. Biophilic design was proposed to provide some design guidance to satisfy this longing for 'nature' in architecture (Almusaed, 2011; Cramer and Browning, 2008; Joye, 2007; Kellert, 2008b; Ryan et al., 2014; Wilson, 2008). Biophilic design explains why some buildings are considered to perform better than others regarding their nature-connectedness (Berkebile et al., 2008). This nature connectedness presents all sorts of benefits in the living, working, learning, entertainment, and medical environments (Abdelaal, 2019; Abdelaal and Soebarto, 2019; Gray and Birrell, 2014; Hähn et al., 2020; Jones, 2013; Mangone et al., 2017; Peters and D'Penna, 2020; Totaforti, 2018; Wallmann-Sperlich et al., 2019). Therefore, biophilic architecture is claimed to contribute to sustainability, overcoming the lack of contact with nature and effectively managing natural resources (Almusaed et al., 2006; Hidalgo, 2014; Jiang et al., 2020; Kayıhan, 2018; McMahan and Estes, 2015).

In summary, there are two main reasons to explore biophilic design. First, the craving for 'nature' is widely recognised in the contemporary built environment; thus, it is essential to provide frameworks to understand 'nature' in architecture. Second, many design concepts related to 'nature' are criticised as 'green-washing' or 'placebo' strategies. Thus, further investigations should be conducted to examine their impacts and effects on sustainable architecture.

1.4. Study overview

This study aims to explore biophilic design as a theoretical framework for conceptualizing 'nature' in architecture and to discuss the ways in which biophilic design contributes to achieving sustainability. In the next section, we introduce the methods we use to select relevant publications and analyse and synthesise these sources. Section 3 investigates how the concept of biophilic design has emerged from relevant theories in environmental psychology and how it has been defined in architecture by key thinkers. Section 4 identifies the crucial elements of biophilic design in contemporary architecture and discusses the potential of biophilic design to address the challenges of sustainable architecture. Section 5 presents a biophilic design framework and illustrates biophilic design strategies, along with the advantages and disadvantages of integrating natural elements into buildings. Finally, the article concludes with the lessons learnt from biophilic design and future directions for research on biophilic design.

2. Method

2.1. Identification of relevant publications

In this review, we adopt diverse searching, screening, and selecting methods. The key terms 'biophilia', 'biophilic design', 'biophilic architecture', and 'biophilic building' are used in the initial search for papers (Fig. 2). Three databases are considered: Scopus, Web of Science, and Google Scholar. The general inclusive criteria set to identify relevant publications are: (1) explained the concept or design strategies of biophilic design; (2) discussed within the scope of architecture, especially urban architecture; (3) examined the impacts of biophilic design through empirical or experimental findings;

(4) related to the goals of sustainability in architecture; and (5) written in English.

For each specific part of the review, search criteria were developed to select relevant literature. In reviewing the theoretical basis of biophilic design, we extracted four relevant concepts (biophilia, habitat and dwelling, restoration, and place) from previous publications. The selection here was relatively rigorous, with literature only included if the discussion of these concepts was significant to the emergence of biophilic design. Other literature on the development of these four concepts was not selected to avoid obscuring the focus on the emergence of biophilic design. In defining the biophilic design, we selected more types of publications (including grey literature) to identify the key frameworks from a wider range of interpretations. Additionally, in interconnecting biophilic design and sustainable architecture and elaborating the pros and cons of different design strategies, the literature review was extended to other relevant subfields in architecture (e.g. materiality, tectonics, mechanical systems, and mobility) to obtain interdisciplinary knowledge. State-of-the-art publications and representative authors were selected wherever possible.

The snowball method as a supplementary search was used to identify publications from the earliest collected literature. Eventually, 141 journal articles, book chapters, and key reports were selected for the review, the majority of which were published between 2010 and January 2021.

2.2. Analysis and synthesis

The study of the obtained publications mainly includes:

2.2.1. Comparative analysis of different taxonomies of 'nature' in biophilic design

The classifications (taxonomies) are closely related to concepts in knowledge organisation, as the ways in which different theories are used to classify a theme correspond to how we conceptualise it (Hjørland and Gnoli, 2017). This study compares different taxonomies of 'nature' in several interpretations of biophilic design to understand the contested notion of 'nature' in architecture. Conceptualisation includes understanding both the features of the concept and the causal mechanisms that link these features (Spiteri, 2008). Thus, we begin with a brief review of the rationale and mechanism of biophilic design. We then select three representative biophilic design frameworks (Browning and Ryan, 2020; Kellert, 2008b, 2018) to conduct the comparative analysis. These three are the most frequently cited frameworks in the literature and are often referenced in building certificates' assessment criteria. The comparative analysis ranges from the purposes of the different elaborations, the specific taxonomic approaches they adopt, to the elements contained therein. Overlaps, similarities, differences, contradictions, and ambiguities are later discussed concerning the synthesis and adjustments of these frameworks.

2.2.2. Comparative analysis of biophilic design and sustainable architecture

This section focuses on what specific challenges in sustainable architecture can be addressed through biophilic designs. We explore the concept of sustainable architecture from the 17 SDGs (UN, 2015). Sustainable architecture serves here as a 'lens' to illuminate how biophilic design contributes to achieving the goals of sustainability in architecture. We aggregate the various benefits of biophilic design discussed in earlier studies and compare them with the challenges in sustainable architecture categorised by the 17 goals. Moreover, we record the most relevant biophilic design elements in this challenge-benefit comparison for the proposed biophilic design framework. We also discuss the opportunities to develop solutions with multiple benefits.

3. Framing biophilic design

Kellert (2008b, p.3), as one of the pioneers of biophilic design, defines it as 'a deliberate attempt to satisfy the need of contact with natural systems and processes in the contemporary built environment, and to improve people's physical and mental health, productivity and wellbeing'. He argues that biophilic design could foster beneficial contact

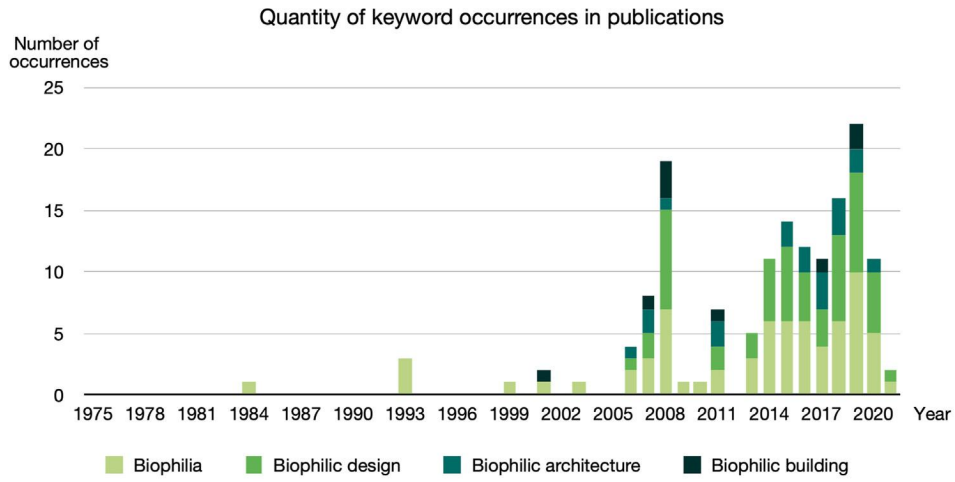

Fig. 2 Year and quantity of keyword occurrences (Source: authors. Note: several different keywords appearing in the same publication were counted several times).

between people and nature, thereby to producing a 'positive environmental impact' (Kellert, 2005, p.107). In other words, biophilic design does not solely focus on reducing the impacts of the building sectors on the environment while lacking interaction with 'nature' (Berkebile et al., 2008). This concept has received widespread attention in the past two decades. Before explaining its key elements and design strategies in practices, we discuss the emergence of the concept of biophilic design.

3.1. Origins of biophilic design

The concept of biophilic design is built upon, but not limited to, the theory of biophilia. Many theories from environmental psychology demonstrate that humans' need for 'nature' is due to an instinctive feeling towards natural elements. Such theories explain the mechanism through which physical and mental functions are generated from contact with 'nature' (Joye, 2007; Peters and D'Penna, 2020; Ryan et al., 2014; Söderlund and Newman, 2015). These theories provide the theoretical foundation for the development of biophilic design (Table 1).

3.1.1. Biophilia

Wilson (1984, 1993) understands *biophilia*, the 'philia' (love) of 'bio' (life or living things), as an emotional response, which is 'innate', 'hereditary', and exists in the genes. Human beings have lived and survived in the natural environment for most of evolutionary history. When we moved to the modern artificial environment, our dependence on nature for survival in primitive times was retained and evolved into seeking connections with nature for 'personal identity' (Kellert, 1993). Therefore, the 'evolutionary dependence on nature' for 'survival and personal fulfillment' forms the basis of biophilia (Kellert, 1993).

3.1.2. Habitat and dwelling

In evolutionary psychology, the emotional need for 'nature' is also explained as inherited affection from the experience of choosing habitats and building dwellings. It is argued that some natural landscapes or spaces were more conducive for our ancestors' survival; thus, some characteristics identified from these 'natural' spaces are also preferred in modern architectural spaces (Appleton, 1975; Hildebrand, 1999, 2008; Orians and Heerwagen, 1992). By consciously arranging these 'natural' characteristics, fascinating nature-like environments can be created.

3.1.3. Restoration

Within the restoration perspective, both theories concern enhancing contact with nature for health and well-being; however, their different mechanisms lead to distinct effects. Stress recovery theory proposes that contact with natural features (e.g. vegetations and water) can generate a quick and positive psychological reaction. Thus, exposure to nature could reduce negative emotions and foster recovery from physiological stress and health problems (Ulrich, 1983; Ulrich et al., 1991). In comparison, attention restoration theory suggests that the cognitive tasks' excessive consumption of human attention leads to brain fatigue and mental stress, and since we do not need to spend much energy on attention when interacting with nature, it can provide opportunities to restore exhausted attention (Kaplan, 1995; Kaplan and Kaplan, 1989).

3.1.4. Place

Place attachment theory examines the emotional connections with places and argues that people tend to stay in more familiar places (Hidalgo and Hernández, 2001). This theory further illustrates that connecting to the local natural environment by incorporating regional features (e.g. geomorphology and landscape) in buildings could generate the 'sense of place' and 'sense of community', thereby realising personal identity, belonging, and cohesion (Manzo, 2003).

Theories from different perspectives support the emergence of biophilic design and converge to suggest that human's craving for 'nature' is deeply ingrained. Although the urge has evolved from the dependence on 'nature' for survival to the preferences for contact with 'nature', the emotional need for 'nature' has been preserved. Nevertheless, not all 'nature' is beneficial to humans (Heerwagen and Hase, 2001). Different from positive affiliations (biophilia), some occurrences of 'nature' that have negative psychological effects, such as the fear of snakes, spiders, the deep sea, and unmeasurable heights, are assigned to another emotion, 'biophobia' (Ulrich, 1993). It is thus essential to discern what kind of 'nature' in architecture can provide positive connections, or in brief, what makes up biophilic design.

3.2. Defining biophilic design

On the theoretical basis of several environmental psychology concepts (as outlined in the previous sub-section), the understanding of the value of contact with 'nature' was translated into the realm of architecture to explain a range of issues concerning the integration of 'nature' in architecture. The concept of biophilic design subsequently emerged. From 2001 on, academics and practitioners developed different interpretations of biophilic design (Fig. 3). These interpretations demonstrate different taxonomies of 'nature' in architecture from categories to elements, in which psychologically experienced and physiologically perceived 'nature' are discussed inclusively.

Heerwagen and Hase (2001) were the first to define various features in biophilic architecture. They attributed various natural qualities into eight characteristics based on habitability, natural elements, process, and geometry in design, as well as joyfulness and enticement. Their framework illustrated that 'nature' could be conceptualised differently in architecture, although it was a tentative work. A few years later, a group of biophilic proponents co-authored the book *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life* (Kellert et al., 2008). In this book, Kellert (2008b) proposed a more systematic interpretation of biophilic design with two basic dimensions, six elements, and over seventy attributes. Heerwagen and Gregory (2008) and Hildebrand (2008) proposed some perceivable and cognisable attributes/characteristics of 'natural' spaces that can be used in spatial layouts to create biophilic buildings. Moreover,

Table 1 Theoretical basis of biophilic design in environmental psychology.

Perspective	Theory	Description
Biophilia	**The Biophilia Hypothesis** (Wilson, 1984, 1993)	Biophilia is 'the innately emotional affiliation of human beings to other living organisms.' After human migrated to the built environment, we inherited a need for nature, which evolved into 'thinking about nature'.
	Biophilia Values (Kellert, 1993)	The dependence on nature is 'for survival and personal fulfilment', and the nine biophilia values are: 'utilitarian, naturalistic, scientific, aesthetic, symbolic, humanistic, moralistic, dominionistic, and negativistic'.
Habitat and Dwelling	**Prospect-Refuge Theory** (Appleton, 1975)	Prospect and refuge occur simultaneously, that is, 'the ability to see without being seen'. Prospect provides 'an unimpeded opportunity to see' (to find and gather sources), and refuge offers 'a shelter to hide' (to be protected from outside threats).
	The Savanna Hypothesis (Orians and Heerwagen, 1992)	The savanna is the mixed woodland and grassland landscape commonly seen in Africa. It affords abundant resources, open views, and climbable trees that are conducive to survival. Today, people still have aesthetic preferences for savanna-like environments.
	The Aesthetics of Survival (Hildebrand, 1999, 2008)	Survival advantageous characteristics are identified to discuss landscape preferences and explain why nature is fascinating in architecture. The five characteristics are: 'prospect and refuge, enticement, peril, and complex order'.
Restoration	**Stress Recovery Theory** (Ulrich, 1983; Ulrich et al., 1991)	Stress Recovery refers to unthreatened exposure to nature that produces positive emotions and contributes to health and wellbeing. It is supported by some preferred natural features (e.g. vegetations, water, and natural structures, textures, images, and vistas).
	Attention Restoration Theory (Kaplan, 1995; Kaplan and Kaplan, 1989)	Attention Restoration helps relieve mental stress and brain fatigue. Interactions with the natural environment do not require much cognitive work, which is beneficial to restoring exhausted attention.
Place	**Place Attachment Theory** (Hidalgo and Hernández, 2001; Manzo, 2003)	Place Attachment Theory explores the emotional connection with places and explains the 'sense of place' and 'sense of community'.

Cramer and Browning (2008) offered three preliminary categories of biophilic building. Drawing on these three categories, the construction consulting firm Terrapin Bright Green outlined fourteen patterns of biophilic design (Browning et al., 2014). Similarly, Kellert and Calabrese (2015) streamlined Kellert's (2008b) first framework and proposed a new one that includes twenty-four attributes within three categories. Later, these two similar frameworks were further revised and updated by their proponents (Browning and Ryan, 2020; Kellert, 2018). Xue et al. (2019) recently suggested the connections with 'nature' from individual (building user health and well-being) to societal (public health) perspectives.

Among the numerous biophilic design interpretations, we chose three representative conceptual frameworks to conduct a comparative analysis (Browning and Ryan, 2020; Kellert, 2008b, 2018) (Fig. 4). These three frameworks are often used as the conceptual basis to establish criteria regarding natural contact/connection in some important architectural certificates (e.g. LBC, WELL, and LEED). They have also been adopted to investigate biophilic design in many other studies (Abdelaal and Soebarto, 2019; Aye et al., 2019; Gillis and Gatersleben, 2015; Park and Lee, 2019; Peters and D'Penna, 2020). However, few studies have discussed the taxonomies of 'nature' in these frameworks and examined whether the terminologies are appropriate to describe 'nature' in architecture more explicitly rather than aggravating the ambiguity.

The overall purpose of all three frameworks is to help designers understand and apply the concept of biophilic design in practice, but these frameworks also differ. Kellert's (2008b, 2018) interpretations are built upon the biophilia theory and biophilia values drawn from evolutionary psychology. In contrast, Browning and Ryan (2020) investigate the human-nature relationships based on biological responses, 'psychological, physiological health and well-being, and cognitive functionality and performance' (Browning et al., 2014, p. 11). In addition, Kellert's (2008b) first framework is introduced as a detailed 'specification' of biophilic design, in which all-inclusiveness is celebrated. This shows the developer's ambition to use this concept as an omnipotent elaboration for understanding 'nature' in architecture. However, the focus shifts from the earlier comprehensive enumeration to a more concise and comprehensible model in the latest frameworks. It is demonstrated in two aspects: the framework structure adopted (categorisations) and the elements contained and categorised.

In terms of categorisations, key proponents reached a consensus recently on providing relatively succinct explanations. Kellert (2008b) initially applied a hierarchical structure from the fundamental distinction (dimensions) to subdivisions (elements and attributes) in his framework. Those that directly, indirectly, or symbolically reflect 'natural' forms are regarded as 'organic or naturalistic' dimensions, while those culturally or ecologically attached

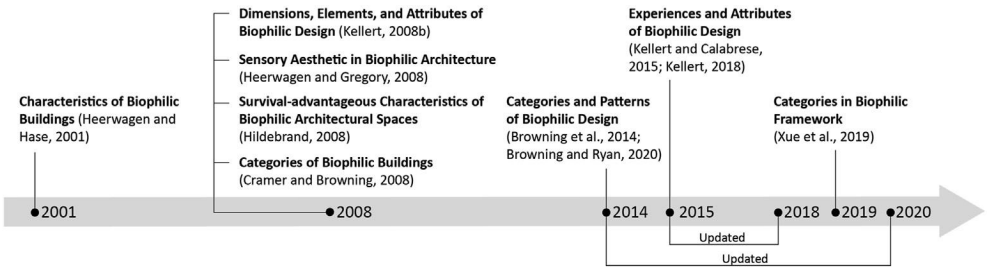

Fig. 3 Timeline of various biophilic design interpretations.

to geographical areas are classified as 'place-based or vernacular' dimensions (Kellert, 2008b). However, this hierarchical taxonomy sometimes causes vagueness, as the linkage between the basic two 'dimensions' and the subsequent categorised 'elements' and 'attributes' was not expounded by Kellert. Thus, he adjusted the three-level taxonomy to two-level by synthesising previous divided 'dimensions' and 'elements' into three 'experiences': (1) 'direct experience of nature', to 'contact with basic features and characteristics of the natural environment'; (2) 'indirect experience of nature', to 'convert empirical and objective reality into symbolic and metaphorical forms through projecting thoughts, images, and feelings'; and (3) 'experience of space and place', to 'the spatial setting', to consider 'how people manage and organise their environmental circumstances' (Kellert, 2018, pp. 24–25). Similarly, Browning and Ryan (2020) divided various physical, metaphorical/representational nature and the emotional reactions of nature into three categories: 'nature in the space', 'natural analogues', and 'nature of the space'.

Nevertheless, ambiguities remain within the two recent frameworks. For instance, Kellert's (2018) 'experience of space and place' is hard to understand terminologically regarding how it relates to contact with nature. This type includes a range of spatial characteristics of nature described as 'sensory aesthetic' or 'survival-advantageous' (Heerwagen and Gregory, 2008; Hildebrand, 2008), as well as the requirement for a sense of belonging in Place Attachment Theory (Manzo, 2003). Producing these effects (pleasurable experiences) requires specific arrangements rather than the mere experience of the common spaces and places. A more explicit expression is therefore needed here. Moreover, in Browning and Ryan's (2020) framework, two of the three patterns under the category of 'natural analogues' can likewise be grouped into the other two categories. 'Material connection with nature' as a physical type can be attributed to 'nature in the space', and 'complexity and order' as a feature or quality can be assigned to 'nature of the space'.

For these categories, Kellert (2008b, 2018) tends to classify diverse nature according to characteristics (concrete, simulated, emotional, or others) and refers to them as 'attributes'. While Browning and Ryan (2020) elaborate on the functional role of nature in architectural design, they thus apply a 'pattern' language derived from an architectural theory book, *A Pattern Language* (Alexander et al., 1977). Although different authors adopt diverse terms, some similar elements are included. For example, 'light', 'air' and 'water' are similar to 'dynamic and diffuse light', 'thermal and airflow variability' and 'presence of water'; 'weather', and 'changes, ages, and the patina of the time' are depicted as 'connection with natural systems'; natural 'shapes and forms' and 'natural geometrics' are suggested as 'biomorphic forms and patterns'; and natural 'materials' are termed as 'material connection with nature'. Additionally, they agree that nature can be experienced psychologically through deliberate spatial arrangements, such as setting 'prospect', 'refuge', 'complexity and order', or 'organised complex' (Browning and Ryan, 2020; Kellert, 2018).

Divergences can also be witnessed in the specific elements argued by different authors. Kellert (2018) suggests 'animals' and 'plants' as two key elements individually because love for 'living organisms' is the core of biophilia theory, and he includes 'fire', as it is believed to play an important role in human survival. Further, Kellert (2018) discusses 'boundary', 'transitional spaces', and 'mobility' in exploring place-based relationships with nature. In Browning and Ryan's (2020) framework, a unique pattern, 'non-rhythmic sensory stimuli', is interpreted as the 'stochastic and ephemeral connection with nature that may be analysed statistically but may not be predicted precisely', like birds' occasional stopover. They also contain the emotional experiences of spaces, like 'mystery', 'risk/peril', and one particular pattern, 'awe', explained as 'stimuli including other biophilic patterns that defy an existing frame of reference and lead to a change in perception' (Browning and Ryan, 2020, p. 5).

Previous frameworks extend/simplify, corroborate, correct, or refine each other. However, we recognize some problems that may make this interpretation intricate and obscure. The first is the overlaps between the elements caused by the dichotomous expression. In the 15 patterns (Browning and Ryan, 2020), 'visual connection with nature' and 'non-visual connection with nature' are independent, while the other 13 are also largely covered by the visual or non-visual patterns. Moreover, repetitions exist in Kellert's (2008b, 2018) classifications, such as the overlap between 'sensory variability' and the elements that deliver multisensory experiences (e.g. water, plants, and weather), and the overlap between 'information richness' overlap and those that represent complex forms (e.g. natural geometries and organised complexity). Furthermore, according to the original definition, only those that generate 'positive environmental impacts' and enhance 'people's physical and mental health, productivity and wellbeing' are subsumed under biophilic design (Kellert, 2008b, p. 3). However, 'fire' is commonly displayed through metaphorical or symbolic manners in contemporary architecture to avoid fire risk,

2 Dimensions, 6 Elements, and 72 Attributes of Biophilic Design (Kellert, 2008b)

I. Organic or Naturalistic				II. Place-based or Vernacular	
1. Environmental features	**2. Natural shapes and forms**	**3. Natural patterns and processes**	**4. Light and space**	**5. Place-based relationships**	**6. Evolved human-nature relationships**
• Color • Water • Air • Sunlight • Plants • Animals • Natural materials • Views and vistas • Façade greening • Geology and landscape • Habitats and ecosystems • Fire	• Botanical motifs • Tree and columnar supports • Animal (mainly vertebrate) motifs • Shells and spirals • Egg, oval, and tubular forms • Arches, vaults, domes • Shapes resisting straight lines and right angles • Simulation of natural features • Biomorphy • Geomorphology • Biomimicry	• Sensory variability • Information richness • Age, change, and the patina of time • Growth and efflorescence • Central focal point • Patterned wholes • Bounded spaces • Transitional spaces • Linked series and chains • Integration of parts to wholes • Complementary contrasts • Dynamic balance and tension • Fractals • Hierarchically organized ratios and scales	• Natural light • Filtered and diffused light • Light and shadow • Reflected light • Light pools • Warm light • Light as shape and form • Spaciousness • Spatial variability • Space as shape and form • Spatial harmony • Inside-outside spaces	• Geographic connection to place • Historic connection to place • Ecological connection to place • Cultural connection to place • Indigenous materials • Landscape orientation • Landscape features that define building form • Landscape ecology • Integration of culture and ecology • Spirit of place • Avoiding placelessness	• Prospect and refuge • Order and complexity • Curiosity and enticement • Change and metamorphosis • Security and protection • Mastery and control • Affection and attachment • Attraction and beauty • Exploration and discovery • Information and cognition • Fear and awe • Reverence and spirituality

3 Experiences and 25 Attributes of Biophilic Design (Kellert, 2018)

1. Direct Experience of Nature	2. Indirect Experience of Nature	3. Experience of Space and Place
• Light • Air • Water • Plants • Animals • Landscapes • Weather • Views • Fire	• Images • Materials • Texture • Color • Shapes and forms • Information richness • Change, age and the patina of time • Natural geometries • Simulated natural light and air • Biomimicry	• Prospect and refuge • Organized complexity • Mobility • Transitional spaces • Place • Integrating parts to create wholes

3 Categories and 15 Patterns of Biophilic Design (Browning and Ryan, 2020)

1. Nature in the Space	2. Natural Analogues	3. Nature of the Space
• Visual Connection with Nature • Non-Visual Connection with Nature • Non-Rhythmic Sensory Stimuli • Thermal & Airflow Variability • Presence of Water • Dynamic & Diffuse Light • Connection with Natural Systems	• Biomorphic Forms & Patterns • Material Connection with Nature • Complexity & Order	• Prospect • Refuge • Mystery • Risk/Peril • Awe

Fig. 4 Three key frameworks of biophilic design (Source: authors, adapted from Browning and Ryan, 2020; Kellert, 2018, 2008b).

especially in high-rises. 'Non-rhythmic sensory stimuli' are often accompanied by the uncertainty of forming unstable psychological responses and distractions. As such, these elements do not meet the criteria for biophilic design.

Hence, to narrow the overlaps of the existing biophilic design frameworks and screen out more vital elements in contemporary urban architecture, we analyse the benefits of biophilic design in mitigating the challenges of sustainability in architecture.

4. Biophilic design for sustainable architecture

This section connects biophilic design with sustainable architecture. Various challenges of sustainable architecture are identified to reflect different design goals, and the benefits of biophilic design are reviewed to investigate the effective design elements. In comparing diverse challenges and rich benefits, the correlation between biophilic design elements and the sustainable goals of architecture is revealed.

Since the 1990s, the concept of sustainability has been widely discussed and explored in the architectural realm. Confronting various environmental crises such as resource scarcity, climate change, and sick building syndrome (Guy and Moore, 2005), distinct sustainable approaches have been explored, ranging for example from applying energy-efficient, high-tech, low-tech and vernacular strategies; analogizing nature and natural systems for design inspiration; or adopting intelligent, responsive, renewable, recyclable and biodegradable materials. These diverse concerns and design approaches defy simple classifications of sustainable architecture, and their 'plurality' has been praised (Guy and Moore, 2007).

Today, 'sustainability' is still considered a contested and ambiguous concept. Schröder (2018) confirms that 'heterogeneity, complexity, conflicts of aims, and controversies are normal'. He suggests exploring what architects, engineers, and clients do with the concept of sustainability in practice through the framework of translation, 'which challenges of sustainability they recognize and how in response to these

Table 2 Benefits of biophilic design in addressing the challenges of sustainable architecture.

	The 17 SDGs	Challenges in Sustainable Architecture	Benefits of Biophilic design	Most Relevant Biophilic Design Elements
*	**1. No Poverty**	- Affordability of housing	- Reduce energy and construction material costs (Lerner and Stopka, 2016)	• Air • Daylight • Plants • Materials, texture, and colour
*	**2. Zero Hunger**	- Food supply	- Enable food production (Söderlund, 2019, p.200)	• Plants
***	**3. Good Health and Well-Being**	- Healthy and comfortable indoor environment - Non-toxic substances and environment - Obstruct disease transmission and bacterial contact - Physical exercise spaces	- Reduce air pollution and optimise air quality (Aydogan and Cerone, 2020) - Optimise thermal comfort (Africa et al., 2019; Hoelscher et al., 2016) - Provide psychological restoration (Berto and Barbiero, 2017; Gillis and Gatersleben, 2015; Lee et al., 2015; Yin et al., 2018) - Reduce stress (Browning et al., 2014) - Increase healing rates (Abdelaal and Soebarto, 2019) - Enhance positive emotions (Mandasari and Gamal, 2017) - Encourage physical activity (Korpela et al., 2017; Wallmann-Sperlich et al., 2019)	• Air • Daylight • Plants • Landscape • Images • Materials, texture, and colour • Prospect and refuge • Enticement (peril and mystery)
**	**4. Quality Education**	- Performance in learning environments - Training and education of sustainable performance knowledge	- Increase cognitive performance (attention capacity, creative performance, and memory restoration) (Abdelaal, 2019; Aydogan and Cerone, 2020; Browning et al., 2014; Hähn et al., 2020; Mangone et al., 2017) - Raise environmental awareness (Boiral et al., 2019; Church, 2015)	• Air • Daylight • Plants • Landscape
*	**5. Gender Equality**	- Inclusiveness of diverse genders	- Provide examples of considering gender in design (Beil and Hanes, 2013; Hähn et al., 2020)	• Plants • Landscape
*	**6. Clean Water and Sanitation**	- Rainwater collection and purification - Resilience in the face of water-related climate change	- Improve water management (stormwater management, water recycling, and water runoff quality) (Vanuytrecht et al., 2014)	• Water • Weather
**	**7. Affordable and Clean Energy**	- Energy consumption of heating or cooling, lighting - Geographical, climatic, and cultural conditions	- Decrease energy consumption (enhance building passive cooling and lessen the perceived temperature) (Dahanayake and Chow, 2019; Hoelscher et al., 2016; Sudimac et al., 2019)	• Air • Daylight • Plants • Weather

(*continued on next page*)

Table 2 (*continued*)

	The 17 SDGs	Challenges in Sustainable Architecture	Benefits of Biophilic design	Most Relevant Biophilic Design Elements
**	**8. Decent Work and Economic Growth**	- Health and productivity of employees in workplaces	- Increase worker productivity (Aydogan and Cerone, 2020; Gray and Birrell, 2014; Hähn et al., 2020) - Increase retail potential (Söderlund, 2019, p.152)	• Mechanisms • Air • Daylight • Plants • Landscape
**	**9. Industry, Innovation and Infrastructure**	- Physical and digital infrastructure development - Stricter building standards in terms of pollution, energy consumption, safety, and health	- Enrich building appearance (Söderlund, 2019, p.52) - Provide examples of the use of virtual reality in design (Yin et al., 2018) - Promote policy or financial incentives (Söderlund, 2019, p.76) - Increase building rating (Jiang et al., 2020; Sheweka and Mohamed, 2012)	• Plants • Time and seasonal changes • Forms and shapes • Patterns and geometries • Mechanisms • Complexity and order
*	**10. Reduced Inequalities**	- Accessibility of public infrastructure (e.g. landscape qualities like a beach or a view) - Inclusiveness for all groups and social responsibility from all members of society	- Provide accessible and public green/blue spaces (Burls, 2007; Well and Ludwig, 2019)	• Water • Plants • Landscape
**	**11. Sustainable Cities and Communities**	- Safety, inclusiveness, robustness, and resilience of cities and settlements - Affordability, accessibility, mobility, and health of houses and infrastructure	- Increase liveability and enable higher density (Littke, 2016; Simpson and Parker, 2018) - Decrease violence and crime (Söderlund and Newman, 2017)	• Water • Air • Daylight • Plants • Landscape • Weather • Connection to place
**	**12. Responsible Consumption and Production**	- Durability and life cycles of the building - Proper use of local materials	- Increase lifespan (Kabisch et al., 2017) - Strengthen the use of indigenous materials and native plant varieties (Kellert, 2018)	• Plants • Materials, texture, and colour • Connection to place
***	**13. Climate Action**	- Climatic comfort with minimum energy consumption - Resilient to changing conditions (e.g. extreme rainfall, floods, hurricanes, drought, and heatwaves) - Sensitivity to local culture, topographic, and climatic conditions - Climate adaptation solutions with co-benefits	- Reduce energy consumption through vegetative climatic effects (Hoelscher et al., 2016; Sheweka and Mohamed, 2012) - Reduce the urban heat island effect (Koc et al., 2017; Kabisch et al., 2017) - Attenuate noise (Rowe, 2011) - Enhance wind protection (Sheweka and Mohamed, 2012) - Sensitive to local topography and climate (Beatley and Newman, 2013)	• Water • Air • Daylight • Plants • Landscape • Weather • Connection to place
*	**14. Life below Water**	- Low-cost water management - Regeneration of polluted land close to the sea	- Reduce water pollution (Rowe, 2011; Söderlund and Newman, 2015)	• Water • Plants • Animals

**	**15. Life on Land**	- Protection, restoration, and support of ecosystems and biodiversity	• Plants • Animals • Connection to place - Improve biodiversity (species diversity preservation and regeneration (Benvenuti, 2014; Fuller et al., 2007) - Provide habitats for animals in urban areas (Africa et al., 2019)
*	**16. Peace, Justice and Strong Institutions**	- Safety, inclusiveness, and affordability of public spaces and institutions	• Plants • Prospect and refuge • All biophilic design elements - Offer public shelter and shade spaces (Hoelscher et al., 2016)
**	**17. Partnerships for the Goals**	- Collaboration among different stakeholders - Associations and networks of professionals	- Present examples of collaboration (e.g. architects and engineers) (Aye et al., 2019) - Allow professional institutions and organisations to work together (Jones, 2016)

(* weakly connected; ** moderately connected; *** strongly connected) (Source: authors).

accepted challenges they construct specific particular sustainability design goals and design targets are constructed to instruct and in order to align the design team when creating buildings.' By bridging various challenges and design intentions or goals, the contested notion of sustainability in architecture can be unpacked and understood.

Biophilic design offers a number of strategies for supporting sustainability in architecture (Almusaed, 2011; Almusaed et al., 2006; Jiang et al., 2020; Jones, 2013; Ryan and Browning, 2018; Wijesooriya and Brambilla, 2021). Different researchers explore this theme through diverse pathways, such as by discussing biophilic design values on the resilience in the face of climate change (Africa et al., 2019; Beatley and Newman, 2013; Fink, 2016) or comparing biophilic design patterns with SDGs (Sharifi and Sabernejad, 2016). Experimental and empirical findings provide evidence for the adoption of biophilic design in sustainable architecture.

To overcome the fuzzy notion of sustainable architecture and develop a more analytical approach and to understand how biophilic design could contribute to the goals of sustainable architecture, we investigate the benefits of biophilic design in addressing the specific challenges. The 17 SDGs (UN, 2015) were determined to guide the path towards a more sustainable future. Mossin and her colleagues (2018) further explained the challenges that should be addressed in architecture. We identify the diverse challenges of sustainable architecture from their interpretation (Mossin et al., 2018). We then aggregate the multitudinous benefits of biophilic design from previous literature and correspond them to specific challenges in sustainable architecture. Moreover, the most relevant biophilic design elements are determined by correlating various benefits with different elements.

It should be noted that the architecture domain does not contribute to the different SDGs at equal levels. The World Green Building Council identified 9 of the 17 SDGs with the highest potential to be achieved through architecture (WGBC, 2016). The result of the ThinkNature research project (funded by the EU Horizon 2020 Research and Innovation Program) also suggest 11 goals that could potentially be met through nature-based design (Somarakis et al., 2019). In our review, goals beyond these 9 or, respectively, 11 are not excluded. They are instead tenuous relevant goals in correlating biophilic design and sustainable architecture.

Table 2 demonstrates the interrelationship between biophilic design and sustainable architecture. The asterisks indicate the degree of relevance of biophilic design contributions to the different SDGs, with the grades marked from the lowest one (*) to the highest three asterisks (***).

From the comparative analysis of these two themes, we find that the multiform benefits of biophilic design address diverse challenges in sustainable architecture. The ranking of contribution relevance shows that two of the seventeen SDGs (Goals 3 and 13) are heavily supported by biophilic design, and eight SGDs (Goals 4, 7, 8, 9, 11, 12, 15, and 17) also directly take advantage from biophilic design in many cases. In contrast, seven SDGs (Goals 1, 2, 5, 6, 10, 14, and 16) generally only benefit from biophilic design's indirect contributions. Examples include developing urban agriculture to produce food for Goal 1 Zero Hunger, conducting appropriate water management to reduce pollution for

Goal 14 Life Below Water, and more. Although biophilic design has limited effects in pursuing these goals, the exploration of indirect benefits provides additional insights for understanding the notion of sustainable architecture.

The benefits could be measurable, not directly measurable, quantifiable, unquantifiable, tangible, and intangible. Many of these benefits are interrelated, although they are discussed from different standpoints. For instance, the proper use of indigenous natural materials cannot only reduce construction costs to reduce poverty (Goal 1) but also contribute to the recycling of materials for more responsible consumption (Goal 12). Reducing air pollution provides environmental benefits and is also related to optimising indoor air quality in health. Additionally, from the challenge-benefit analysis, some priorities (e.g. air, daylight, plants, and landscape) in biophilic design are uncovered in achieving multiple sustainable goals. Facing climate change, we need to explore more solutions with co-benefits for sustainable architecture (Barron et al., 2019; Mossin et al., 2018). Therefore, more qualitative and quantitative research is required to identify biophilic design strategies and guidelines in developing efficient solutions and support the enactment of criteria.

5. Biophilic design approaches and elements

5.1. A biophilic design framework

This study introduces an optimised biophilic design framework to support the integration of 'nature' into architecture in the pursuit of sustainability. The framework consists of three essential design approaches and covers eighteen key elements (Fig. 5). In organising the new biophilic design framework, we elaborate upon the existing frameworks by using taxonomy curation methods such as corrections/renaming, additions/exclusions, and overall revisions and editing (Sancho-Chavarria et al., 2020). We interpret design approaches and elements to make the concept of biophilic design more tangible for architects and other design professionals. We carefully extract the most important biophilic design elements from the various identified types of 'nature': direct or indirect, tangible or intangible, morphological or material, and many others. Those that might cause excessive uncertainty and controversy in terms of effectiveness and those that rarely appear in contemporary urban architecture are rejected. Although it is impossible to eliminate overlaps and repetition, we modify the contained elements terminologically. Terms that are relatively parallel in characters are used in each category.

It should be acknowledged that this framework is a preliminary interpretation of biophilic design. Further transformations are necessary to materialise the concept of biophilic design into practices. Thus, architectural design issues such as form, typology, scale, proportion, tectonics, and technology should be investigated in future studies. The next sub-section presents some design strategies that can be used to apply diverse biophilic designs in architecture.

5.2. Biophilic design strategies and examples

Proponents of biophilic design have suggested many design strategies, priorities, and considerations. Some of these were discussed at different scales in cities (Beatley and Newman, 2013; Salingaros and Madsen, 2008; Wilson, 2008). Some concerned indoor environments (McGee and Marshall-Baker, 2015) or specific buildings (Lee and Park, 2018; Peters and D'Penna, 2020). Some were extracted

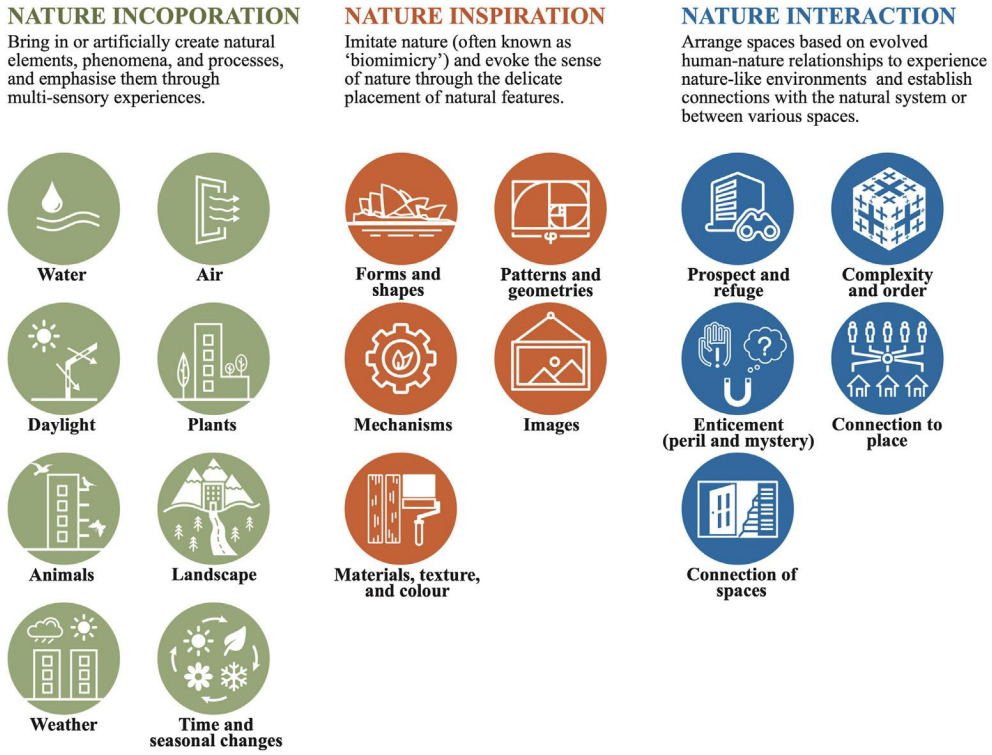

Fig. 5 Biophilic design framework: three design approaches and primary elements (Source: authors).

Table 3 Biophilic design strategies and the positive and negative effects of each element (BDEs: Biophilic Design Elements).

BDEs	Design Strategies	Strengths & Opportunities	Weaknesses & Threats	Examples
Water	• Build waterscapes such as fountains, constructed wetlands, ponds, water walls, rainwater spouts, aquaria, etc. • Access to natural water features such as waterfalls, rivers, streams, oceans, etc. (Browning et al., 2014; Kellert, 2018)	- Create multiple sensory experiences of water, and diverse water configuration and appearance - Expand the water area - Prioritise fluctuating water over stagnant water (Browning et al., 2014; Hunter et al., 2010; White et al., 2010)	- High-volume and large-turbulence water that affects acoustic quality and humidity - Negative (biophobic) emotional responses (e.g. fear of deep water) - Artificial water features may increase energy consumption (Browning et al., 2014; Ulrich, 1993)	 Apple's Piazza Liberty Store, Milan (Italy), by Foster + Partners, built in 2018
Air	• Increase natural ventilation using operable windows, vents, narrower structures, etc. • Simulate natural air and ventilation through operable windows, vents, airshafts, porches, clerestories, HVAC systems, etc. (Browning et al., 2014; Gou et al., 2014; Kellert, 2018)	- Enrich sensory variability and reduce boredom and negativity by imitating the subtle changes of natural air and ventilation - Broaden the acceptable range of thermal comfort to decrease energy demand (Browning et al., 2014; Nicol and Humphreys, 2002)	- Natural ventilation may increase the circulation of pollutants (e.g. PM2.5) - Ventilation when outdoor humidity is high will bring excess moisture that increases the risk of mould contamination Shi et al., (2018)	 Mountain Restaurant & Bar, Zunyi (China), by ZJJZ Atelier, built in 2018
Daylight	• Bring in natural light via glass walls, clerestories, skylights, atria, reflective colours/materials, etc. • Mimic the spectral and ambient qualities of natural light, such as by arranging multiple low-glare electric light sources, ambient diffused lighting on walls/ceiling, and daylight preserving window treatments (Browning et al., 2014; Kellert, 2018)	- Dynamic lights and shadows form transitions between indoor and outdoor spaces, which are fascinating - High-contrast lights bring attention and evoke a sense of sacredness - Support productivity and boost retail sales (Aries et al., 2015; Browning et al., 2014; Cramer and Browning, 2008; Hähn et al., 2020; Hraska, 2015; Lotfabadi et al., 2016; McGee and Marshall-Baker, 2015; Söderlund, 2019, p. 152; Yoon and Lim, 2020)	- Glares and spilling light interfere with visual performance, and intense dynamics might be distracting - Could lead to overheating and decreased building performance (Browning et al., 2014; Cramer and Browning, 2008)	 Institut du Monde Arabe, Paris (France), by Ateliers Jean Nouvel, built in 1987

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Table 3 (*continued*)

BDEs	Design Strategies	Strengths & Opportunities	Weaknesses & Threats	Examples
Plants	• Bring vegetation indoors by potting plants and indoor green walls • Incorporate plants into buildings by using green roofs, green walls and facades, large atria with park-like settings, green pockets, etc. (Chang and Chen, 2005; Kellert, 2018)	- Increase green space coverage, native plants ratio, and biodiversity - Improve shading/sheltering ability and reduce building energy consumption - Edible plants promote food production for urban farming - Provide accessible green spaces and support physical exercise - Provide visual connections with green spaces for restoration, stress reduction, productivity, and positive mood - Reduce air pollution and optimise air quality (Aydogan and Cerone, 2020; Barton and Pretty, 2010; Grinde and Patil, 2009; Hoelscher et al., 2016; Korpela et al., 2017; Maes et al., 2016; Söderlund, 2019)	- Could cause structural problems, excessive humidity, insect trouble, odour issues, etc. - Single plants and isolated gardens have limited impacts - Highly artificial designs require intensive energy and maintenance (Barton and Pretty, 2010; Kellert, 2018; Maes et al., 2016; Oldfield et al., 2015; Revell and Anda, 2014)	 Museé du Quai Branly, Paris (France), by Patrick Blanc, built in 2004
Animals	• Create spaces to accommodate animals, such as ponds, aquariums, etc. • Build animal-friendly living areas to attract animals like nest boxes, gardens, green roofs/walls, etc. Kellert (2018)	- Increase biodiversity and enrich local species - Form an ecosystem with interconnected plants, soil, water, and geological features (Kellert, 2018; Maes et al., 2016)	- Contact with some specific animals (e.g. snakes and spiders) or the sight of dead animals may cause negative (biophobic) emotions Ulrich (1993)	 Mellor Primary School, Stockport (UK), by Sarah Wigglesworth Architects, built in 2015
Landscape	• Build landscapes in the sites such as constructed wetlands, grasslands, prairies, forests, and other habitats • Create interior landscapes in atria, courtyards, entry areas, hallways, etc. • Provide window views of natural landscapes like forests, seascapes and water motifs (Kellert, 2018; Schweitzer et al., 2004; Xue et al., 2019)	- Enhance coherent and ecologically connected landscapes - Optimise the natural landscape, and minimise management requirements (Hwang and Yue, 2015; Kellert, 2018)	- Contrived superficial decorations, isolated, exotic plant configurations - Lack of participation and immersion - Lack of shelter and inappropriate distance and height to view the landscape Kellert (2018)	 Chichu Art Museum, Naoshima island (Japan), by Tadao Ando, built in 2004

Weather	• Enhance exposure to weather through operable windows, porches, balconies, terraces, courtyards, etc. • Enhance awareness of meteorological conditions by using transparent roofs, rainwater collectors and spouts, etc. • Simulate the experience of weather, like sunlight, airflow, humidity, temperature, and barometric pressure Kellert (2018)	- Allow visual access to weather (more cost-effective) and physical experiences to perceive weather - Optimise window views - Adopt permeable surfaces for stormwater management - Integrate rainwater treatment systems into landscape design (Beatley, 2011; Browning et al., 2014; Vanuytrecht et al., 2014; Xue et al., 2019)	- Extreme weather conditions and climate change are not beneficial to human health and comfort Coren and Safer (2020)	 Sun Rain Rooms, London (UK), by Tonkin Liu Architects, built in 2017
Time and Seasonal Changes	• Present the views of the building facade and appearance that change after long-term exposure to nature • Provide views of seasonal changes in plants Kellert (2018)	- Create a sense of maturity (e.g. materials weathered over time) to resist the inauthentic and unreliable feeling of the artificial environment - Provide various sensory experiences (Kellert, 2018; Park and Lee, 2019)	- Building envelopes may be damaged or become dilapidated over time - Perception of seasonal changes depends on individual preferences - Differences in the visual effects of plants in different seasons cause instability Eroğlu et al., (2012)	 Bosco Verticale, Milan (Italy), by Stefano Boeri Architects, built in 2014
Forms and Shapes	• Imitate the contours and motifs of organisms (biomorphic design) in building forms, structural systems, components, and interior spaces • Biomorphic elements could be botanical/animal motifs, shells, spirals, egg, oval, tubular forms, arches, vaults, domes, etc. (Browning et al., 2014; Joye and Loocke, 2007; Kellert, 2008b, 2018)	- Create the cultural and ecological connections with surrounding environments in the expression of form and aesthetics - Enrich architects' creativity (Kellert, 2018; Pawlyn, 2019)	- Overuse and repetition of forms and shapes can cause visual boredom Browning et al., (2014)	 Metropol Parasol, Seville (Spain), by J. Mayer H. Architects, built in 2011

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Table 3 (*continued*)

BDEs	Design Strategies	Strengths & Opportunities	Weaknesses & Threats	Examples
Patterns and Geometries	• Adopt fractals, hierarchically organised ratios, and scales in designs • Use the Fibonacci series (0, 1, 1, 2, 3, 5, 8, 13, 21, 34 …) or Golden Ratio (1:1.618) • Choose the intermediate ratio (1:1.3—1.75) (Browning et al., 2014; Md Rian and Sassone, 2014; Ramzy, 2015a)	- Construct in two/three dimensions (such as floors, walls, furniture, windows and arches) to increase the variety - Use computers to generate complex shapes and structures and allow the use of novel materials - Simultaneously increase structural efficiency and aesthetic appeal - Generate visual complexity (Browning et al., 2014; Md Rian and Sassone, 2014; Ramzy, 2015b; Vaughan and Ostwald, 2010)	- Complex architectural shapes often require higher budgets - May cause chaos and disorder in the building, and make residents feel uncomfortable and unpleasant El-Darwish (2019)	 Agri Chapel, Nagasaki (Japan), by Yu Momoeda Architecture Office, built in 2016
Mechanisms	• Learn from other species to meet the functional needs (Biomimetic or Biomimicry), such as termites and spiders inspired the efficiency of climatic controls and the structural strength of building materials. (Kellert, 2018; Yuan et al., 2017)	- Enhance building performance in terms of indoor comfort and energy consumption - Improve the efficiency of building resources and the ability to self-compensate and regulate - Innovate building shape and structural design (e.g., large span structure, thin shell structure, or membrane structure, etc.) - Improve the durability of the building (Kellert, 2018; Yuan et al., 2017)	- Inevitable human error in mimicking nature may cause an unbalanced system and further endanger the whole larger ecosystem - Focus on imitation of external form and silhouette, but neglect economy and feasibility in structure and construction (Yuan et al., 2017)	 Beijing National Aquatics Center, Beijing (China), by PTW Architects, CSCEC, CCDI and Arup,built in 2007
Images	• Present natural scenes, plants, animals, water, landscapes, or geological features in paintings, photographs, videos, and fabrics. • Natural images should include a rich variety of species, landscapes, or human survival experiences in nature.	- Provide opportunities to connect with nature in special enclosed environments (e.g. radiation rooms in hospitals) - Generate positive distractions to release anxiety, fear, and stress - Evoke a sense of nature-connected	- May be less effective than viewing real natural scenes - Some images produce undesirable effects (e.g., barren/degraded nature or themeless, isolated, random elements) - Influenced by personal preference for natural image types	 Erasmus MC Hospital, Rotterdam

	(Browning et al., 2014; Kellert, 2018)	(Berman et al., 2008; Kellert, 2018; McGee and Marshall-Baker, 2015; Ulrich, 1981; Vaughan and Ostwald, 2010; Yin et al., 2020)	(Browning et al., 2014; de Groot and van den Born, 2003; Kellert, 2018)	(Netherlands), by EGM architects, built in 2018
Materials, Texture, and Colour	• Adopt natural materials like wood, bamboo, rock, stone, clay, etc. • Consider textures beyond materials, such as light, colour, and sound • Use natural colours such as blue, green, and other earth colours (Kellert, 2018; Tsunetsugu et al., 2007)	- Arouse the impression of natural variability by using different materials and colours - Allow rough and unfinished textured surfaces - Replace steel, concrete, etc. as building materials in reducing carbon footprint and promoting sustainability - Bend/curve natural materials to create organic shaped buildings	- The effectiveness of the colour (green) design in real environments is uncertain - Excessively bright or high-contrast colours produce pressure effects, and some colours (e.g., rotting brown) generate negative associations - Disputes exist between unprocessed, crafted, and synthetic natural materials	 Panyaden School, Chiang Mai (Thailand), by 24H $>$ architecture, built in 2010
Prospect and Refuge	• Conceive spaces with two complementary characteristics: open views/vistas (prospect), and under shelters/safe environments (refuge) • Achieved inside and outside experiences through window views, and balconies, courtyards, colonnades, etc. • Use controllable lighting to design spaces with refuge effects (Bloomer, 2008; Browning et al., 2014; Kellert, 2018)	(Kellert, 2018; Nurdiah, 2016) - Provide open views and a sense of closure for simultaneous pleasure and safety - Consider multi-functional prospect-refuge spaces to meet the needs of different activities - Build attractive scenes by providing prospects - Help recover from stress and mental fatigue - Effects can be enhanced by additional complexity and mystery (Browning et al., 2014; Dosen and Ostwald, 2013, 2016; Gatersleben and Andrews, 2013)	Kellert (2018) - Prospect requires focal lengths $\geq$ 6 m, preferably 30 m, and partition heights $\leq$ 107 cm - The balance between prospect and refuge is difficult to define - View qualities depend highly on the surrounding environments (e.g., the view of a lake is considered much more comfortable than that of a glacier). (Browning et al., 2014; Dosen and Ostwald, 2013; Mumcu et al., 2010)	 Arango Marbrisa House, Acapulco (Mexico), by John Lautner, built in 1973
Complexity and Order	• Arrange rich details and diversity in an orderly manner • Consider natural forms, patterns, and geometries, especially in exposed building structures, facades, and details • Choose materials with specific textures and colours or carefully	- Enhance information richness in masterplans, landscapes, building forms/structures, and materials - Arouse visual interest and preference - Use computer algorithms to perform mathematical and geometric operations	- Boredom may be caused by repeated fractal geometry - Lack of consensus on the quality of visual and experiential richness and complexity - Distinct fractal dimensions lead to differences in effects (most consider 1.3–1.5 is comfortable, and 1.5–1.7 is more interesting)	

(*continued on next page*)

Table 3 (*continued*)

BDEs	Design Strategies	Strengths & Opportunities	Weaknesses & Threats	Examples
	arrange the variety and placement of plants (Browning et al., 2014; Kellert, 2018)	- Strengthen the aesthetics of building facades (Abboushi et al., 2019; Browning et al., 2014; Van den Berg et al., 2016; Whang, 2011)	(Abboushi et al., 2019; Browning et al., 2014; Dosen and Ostwald, 2013)	King's Cross Station, London (UK), by John McAslan + Partners, built in 2012
Enticement (Peril and Mystery)	• Generate 'peril' using cantilevers, infinity edges, transparent facades, pathways under/over water, scenes defying gravity, etc. • Create 'mystery' through winding paths, translucent materials, imperceptible sound sources, obscuring/curving the edges, etc. (Browning et al., 2014; Kellert, 2018)	- Produce aesthetic attraction - Enhance mystery by slowly revealing spaces or create dramatic shadows - Opportunities to enrich landscapes and plants (Browning et al., 2014; Heerwagen and Gregory, 2008; Hildebrand, 2008)	- Creating experiences of peril carries risks of physical injury - Sense of insecurity can lead to psychological discomfort - Not applicable to all users and locations - Increases maintenance costs in landscaped gardens (Browning et al., 2014; Dosen and Ostwald, 2013)	 Los Angeles County Museum of Art, Los Angeles (US), by Michael Heizer, built in 2012
Connection to Place	• Provide views of prominent landmarks, landscapes, waterscapes, geological forms, etc. • Use indigenous materials and native plant varieties • Apply landscape features to define building forms or dedicated landscape design such as Savanna-like environments (Kellert, 2008b, 2018)	- Establish connections through various dimensions (e.g., culture, history, geography, and ecology) - Generate a 'sense of place' and satisfy preferences for familiar places (place attachment) - Evoke a sense of belonging and support self-identity by integrating parts into the whole (nature bonding) - Support relaxation and psychological comfort and security (Colding et al., 2020; Hashemnezhad et al., 2013; Kellert, 2008b, 2018; Raymond et al., 2010; Scannell and Gifford, 2017; Tang et al., 2015)	- Misunderstanding of culture and context can lead to inappropriate information or abuse - A sense of loss may be evoked when the designs change negatively or are demolished (Liu et al., 2018; Mazumdar, 1995)	 Ningbo Historic Museum, Ningbo (China), by Amateur Architecture Studio, built in 2008

Connection of Spaces	• Conceive interior-exterior connections in transitional spaces, such as porches, patios, balconies, courtyards, pavilions, gardens, entry areas, foyers, atria, etc. • Consider mobility in spaces like entrances, exits, corridors, stairs, high glass elevators, etc. (Kellert, 2008b, 2018)	- Enhance spatial order and create sequential connections of spaces with clear boundaries, ideal patterns of movement, and the overall identity - Blur interior-exterior boundaries to draw nature into the building - Encourage mobility (promenading) to avoid sedentary situations - Enable interaction within the building by reaching differently designed natural scenes via paths or ramps (Alvaro et al., 2016; Kellert, 2018; Lau et al., 2014; Yoon and Lim, 2020)	- Transitional spaces are complex and involve multiple challenges for design, construction, and maintenance - Single-function paths can create monotony and boredom Lau et al., (2014)	 Frey House II, Palm Springs (US), by Albert Frey, built in 1964

from historical architecture (Ramzy, 2015a), and others were based on different attributes or patterns (Browning et al., 2014; Kellert, 2018).

Table 3 compiles biophilic design strategies used in architecture and elaborates upon the 18 elements in the proposed biophilic design framework. The positive and negative effects of these elements in the building are also discussed in the 'Strength & Opportunities' and 'Weaknesses & Threats' columns. Design cases are collected to illustrate each design element.

Designers should possess interdisciplinary knowledge and choose appropriate design strategies according to their design goals or expected outcomes, such as potential physical and psychological reactions (Browning et al., 2014). However, in investigating the benefits of biophilic design, most previous research overlooked the diversity of such practices and failed to link the impacts with the effective elements. Such generalised interpretations obscure the multiformity of biophilic design approaches and elements, which are obstacles to transforming this concept into practice. Furthermore, applying these elements call for knowledge from many subfields in architectural research, such as materiality, tectonics, mechanical systems, and mobility; however, these subfields are rarely linked in biophilic design studies. Therefore, it is necessary to associate design targets with specific biophilic design elements and invite more specialists in relevant fields to participate in the applicable guideline development.

6. Discussion and conclusion

This review critically explores the concept of biophilic design: how it emerged, how it is defined, in what ways biophilic design can contribute to the goals of sustainability in architecture, and what the major design strategies are. We first investigated the fundamental theories and several key interpretations of biophilic design. We then compared and interconnected the various benefits of biophilic design and the multiple challenges in sustainable architecture. We suggested a biophilic design framework and compiled design strategies, gathering the pros and cons of the different natural elements in architecture.

6.1. Lessons learnt from the review

'Nature' itself is a contested and ambiguous notion, and some argue that it has been idealised and seen as separate from humans, especially since the Romantic period (Beck, 1999; Morton, 2007). To overcome the problematic separation of humans and nature, humans have substantially transformed their environments to enter a mode of being in which humans and nature are more connected. In this article, we have unpacked and explained 'nature' in architecture through the concept of biophilic design. Many proponents of biophilic design suggest that the preference for 'nature' is an instinct that evolved from historical human survival experiences. This perspective echoes the craving for human-nature connectedness seen today and is often represented as the integration of 'nature' into buildings. There is a consensus among key contributors to biophilic design regarding the classification of various

natural elements in architecture into three types based on different design 'patterns' or nature 'attributes'. Still, uncertainties, controversies, and overlaps remain in previous taxonomies. For example, vague terms like 'information richness' and 'non-rhythmic sensory' are used; binary taxonomies like 'visual connection with nature' and 'non-visual connection with nature' are adopted; and some detailed elements are placed alongside collective design methods in the same group, such as 'images', 'colour', 'materials', and 'biomimicry' (including design methods inspired by nature) (Browning and Ryan, 2020; Kellert, 2018). Therefore, we synthesised the previous framework, identified the key elements, and made terminological adjustments. We introduced three biophilic design approaches (nature incorporation, nature inspiration, and nature interaction) and eighteen primary elements selectively in a new framework.

The biophilic design framework encompasses distinct but interrelated elements. First, the boundaries between different biophilic design categories are fluid, and the elements are often interdependent. In order to integrate plants into buildings, we also need to consider water, air, sunlight, animals, weather, and seasons to support vegetative life; regularly trim plants to ensure their growth; create refuge spaces by tree canopies; use indigenous plant species to connect to the local environment; carefully design transitional spaces between the indoors and outdoors to prevent disconnections with the whole ecosystem; and many others. Second, biophilic design encourages the combination of different approaches and elements. As many similar green roofs and walls have recently been constructed, a phenomenon of 'universalisation' has emerged in the greening tendency of sustainable buildings. The mixture of diverse biophilic elements enriches creativity and helps resist such universalisation in sustainable architecture. In BREEAM-NL, buildings including more biophilic design patterns have a better chance of being marked as 'exemplary' rather than 'standard' performance. Furthermore, biophilic design is not simply the expression of natural elements. Some issues, such as whether larger-scale/volume three-dimensional green spaces can boost performance and improve building quality, are largely overlooked. Investigations into the correlation between quantity and quality can help understand more complex design typologies and improve building quality.

Biophilic design has the potential to contribute to sustainability in architecture in many ways. In comparing the specific challenges of sustainable buildings with various benefits of biophilic design, we have revealed that most of the benefits of biophilic design directly or indirectly address these challenges. Direct responses include, for example, decreasing the urban heat island effect (climate action), providing habitats for plants and animals and improving biodiversity (life on land), reducing air pollution, optimising air quality, optimising thermal comfort, and utilising non-toxic substances for healthy indoor environments (good health and well-being), among others. Indirect responses include, such as enabling urban farming for food production (zero hunger), offering accessible and public green or blue spaces, and improving the accessibility of public infrastructures (reduced inequalities). Some design elements like air, daylight, plants, and landscape can be used to address multiple challenges. Thus, consistent with the findings of previous studies (Sharifi and Sabernejad, 2016), we agree that biophilic design may help achieve the goals of sustainable architecture, as biophilic elements could be developed as nature-based solutions with co-benefits especially for enhancing health and well-being and combating climate change.

'Natural' designs are double-edged swords that become 'risk, danger, and side-effects' (Beck, 1999, p.19). However, the negative aspects of incorporating nature into buildings have rarely been discussed in previous publications. Bringing nature into architecture involves careful planning and maintenance. For example, plants may cause structural problems, excessive humidity, insect troubles, and odour issues, or they may simply die, and highly artificial 'green' designs require intensive energy use and maintenance (Barton and Pretty, 2010; Maes et al., 2016; Oldfield et al., 2015). We therefore specify the advantages (strength and opportunities) and disadvantages (weaknesses and threats) of these natural elements in buildings in biophilic design strategies.

The successful and effective practices of biophilic design involves many crucial factors. Design solutions should consider specific user groups. For example, in hospitals, the requirements of distinct groups such as medical workers, patients, and patients' family members should be inclusively considered. Age and gender should also be used as design considerations. Similar to the design of learning environments, different concerns should be given for children and university students. Gender should also be considered, as women may have stronger psychological responses to plants than men (Grinde and Patil, 2009). Furthermore, exposure time to 'nature' and contact frequency should be quantified and weighed in design. Spending at least 120 min a week in urban green spaces improves people's health and well-being (White et al., 2019), while the 40-s viewing of green roofs produces micro-breaks that can restore attention (Lee et al., 2015). Quantitating scale is another important consideration. Single or isolated plants have limited effects (Kellert, 2018), while huge quantities of greening may also become a burden due to additional building materials, structural requirements, and maintenance budgets.

6.2. Evaluation of biophilic architecture

Biophilic design should not be limited to promising ideas without scientific substantiation; such ideas need to be evaluated and quantified. However, the quantitative evaluation of biophilic architecture is a significant challenge (Ryan et al., 2014). On the one hand, many relatively subjective factors are difficult to measure. On the other

hand, biophilic design is a relatively new topic and lacks quantitative studies. Although the focus of this study is not to develop assessment criteria, identifying quantitative indices could help architecture specialists become further involved in biophilic design. Some indices are listed here for consideration: water area size, humidity level, noise level, air ventilation rate, air supply rate, CO_2 level, temperature, daylight factor, daylight autonomy, plant and animal species numbers (biodiversity level), accessible green space area and rate, viewable green space area and rate, tree canopy scale, indoor plant size and density, natural material type and quantity, colour brightness and contrast, focal lengths in prospect, and fractal dimension in complexity.

However, quantitative analyses have limitations; many factors related to environmental psychology, such as the sense of belonging, the fulfilment of personal identity, and the satisfaction of aesthetic preferences, are difficult to quantify. Both qualitative and quantitative indices are provided in the evaluation criteria of some building certificates (see Appendix). Within the broad range of biophilic design, the indices developed rarely exceed the physical natural elements like water and green spaces. Therefore, to establish a scientific evaluation system for biophilic design, investigations of architectural themes such as typology, form, scale, composition, order, tectonics, and technology should be extended.

In addition, as discussed, the integration of 'nature' in architecture is not a recent occurrence. The biophilic design framework suggested in this study, which encompasses a wide variety of design approaches and elements, provides a method for re-examining and re-evaluating how 'nature' was (consciously) embedded into many compelling designs before the emergence of biophilic design. 'Biophilia' is a quality that is also present in historical architecture (Ramzy, 2015a). Though such structures may not have been designed with the concept of biophilia in mind, they still show the architects' concerns and endeavours to connect with nature. For instance, the Japanese Zen Garden in Ryōan-Ji is a good illustration of traditional architecture that coexists with nature through metaphorical natural landscapes; the Humble Administrator's Garden in China mimics the richness information of nature through different combinations of stones, plants, architecture, and water; the Saint Basil's Cathedral in Moscow recalls natural shapes and forms; and the Milan Cathedral is an example of the incorporation of natural patterns and geometries. Moreover, prominent biophilic designs can be seen in modern architecture such as the Great Workroom of the Johnson Wax Headquarters (designed in 1936) and the Sydney Opera House (designed in 1957).

6.3. Future research

As biophilic design has been applied in architecture for only 20 years, many unanswered questions remain. The concept of biophilic design provides many inspirations for architectural design, but architectural language (e.g. typology, order, and context) is rarely used to interpret biophilic buildings. Future research should analyse cases from architectural perspectives by considering tectonics, form, technology, and representation. For instance, how biophilic design enriches architectural forms? How should biophilic design be explained typologically? How does it enhance spatial organisation and order? How does it relate to the site and the context? The biophilic design framework still lacks explicit design strategies and guidelines to translate these approaches or elements into architectural design, as only general strategies and considerations of biophilic design can be derived from the existing literature. In addition, it is crucial to identify design targets or desired responses (Browning et al., 2014). Biophilic design guidelines require more interdisciplinary knowledge to link design strategies and benefits. Other themes, such as the collaboration between distinct professions (Aye et al., 2019) and the discussion of financial matters (Littke, 2016), remain in design considerations. Building technology is also essential to the materialisation of biophilic architecture. Further investigations should focus on not only how to construct such buildings but also how to reduce or address their defects. Another question concerns validating the effectiveness of biophilic design, especially for unmeasurable benefits without concrete metrics. Thus, further qualitative and quantitative research is necessary to evaluate the performance of biophilic buildings. Furthermore, as integrating nature into buildings ('greening' of architecture) becomes a marketing tool, the crucial factors of biophilic design must be examined and given critical attention.

In conclusion, this study explicates the distinct features, design approaches, and elements of 'nature' in conceiving biophilic architecture and bridges the benefits of biophilic design and specific challenges of sustainable architecture. The biophilic design framework embraces a wide variety of 'natural' design, from physical, sensory, metaphorical, morphological, material to spiritual experiences. Some elements (e.g. air, daylight, plants, and landscape) present opportunities to develop design strategies with multiple benefits, especially for enhancing health and well-being, productivity, biodiversity, circularity, and resilience. A comprehensive understanding of biophilic design can help to enrich creativity and organise spatial experiences, which contributes to design innovation and enhances building quality in the pursuit of sustainable architecture.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Biophilic design in building certification systems

Building Standards	Published Year	Qualitative Evaluation of Biophilic Design	Quantitative Evaluation of Biophilic Design	Sources
WELL V2	**2020**	**Mind - Biophilia I Qualitative:** 1. Nature Incorporation (environmental elements, lighting, space layout) 2. Pattern Incorporation (nature's patterns throughout the design) 3. Nature Interaction (within the building, within the project boundary, external to the building)	**Mind - Biophilia II Quantitative:** 1. Outdoor Biophilia (25 % of the site area with landscaped grounds or rooftop gardens, and 70 % plantings including tree canopies) 2. Indoor Biophilia (potted plants or planted beds $>$ 1 % of floor area per floor, and covering a wall area $\geq$2 % of the floor area) 3. Water Feature (at least one water feature for every 9290 m^2 [100,000 ft^2] in projects larger than 9290 m^2 [100,000 ft^2], each one $>$1.8m in height or 4 m^2 in the area and with technology to address water safety)	https://standard.wellcertified.com/mind/biophilia-ii-quantitative
BREEAM-NL V1.0 (NC)	**2020**	**Health - HEA 10 Biophilic Design:** Browning et al.'s 14 patterns of biophilic design in 3 categories: 1. Direct Experience of Nature 2. Indirect Experience of Nature 3. Experience of Space and Place	**Health - HEA 10 Biophilic Design (standard):** From Browning et al.'s 3 categories and 14 patterns of biophilic design 1. At least 1 of the 3 categories are included 2. At least 7 of the 14 patterns are included 3. In 80 % of the living spaces, at least 2 patterns can be directly experienced while the other 5 patterns can be experienced on the same floors 4. No significant negative effect on the main health aspects 5. At least 3 measures (patterns) are not typical for the building and user function in which they are applied	https://richtlijn.breeam.nl/credit/biophilic-design-1092
GM (NRB and RB)	**2015, 2016**	**NRB 2015 4.2c Wellbeing - (i) Biophilic Design:** 1. Accessible sky gardens, sky terraces, internal courtyards and rooftop gardens as areas 2. Biomimicry designs 4. Natural shapes and forms, or ecological attachment to the place	**NRB 2015 4.2c Wellbeing - (i) Biophilic Design:** 3. $\geq$ 5 % of the common areas or functional spaces fix indoor planting 5. Images of nature for 5 % of common areas	https://www.bca.gov.sg/Greenmark/others/Green_Mark_NRB_2015_Criteria.pdf https://www.bca.gov.sg/GreenMark/others/GM_RB_2016_criteria_final.pdf

		RB 2016 4.02 c Wellbeing - (i) Biophilic Design: 1. Nature in common areas 2. Indirect experience of nature 3. Experience of space and place 4. Space in common areas for lifestyle wellbeing	
LBC 4.0	**2019**	**Health + Happiness - Access to Nature:** 1. Sufficient and frequent human-nature interactions in both the interior and the exterior 2. Post-occupancy evaluation regarding daylight, fresh air and access to nature **Beauty - Beauty + Biophilia:** 1. Environmental features, light and space, and natural shapes and forms 2. Natural patterns and processes and evolved human-nature Relationships 3. Place-based relationships (place, climate, and culture) 4. Human delight, and culture, spirit, and place	https://living-future.org/biophilic-design/#the-initiative
LEED V4 (BD+C NC)	**2018**	**Pilot Credits EQpc123 - Designing with Nature, Biophilic Design for the Indoor Environment:** 1. Nature in the space (or environmental features, light and space, natural patterns and processes) 2. Natural analogues (or natural shapes and forms) 3. Nature of the space (or evolved human-nature relationships) 4. Place-based relationships 5. Opportunities for human-nature interactions	https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthc-147?return=/pilotcredits/Commercial-Interiors/v4

(NC: New Construction; NRB: Non-Residential Building; RB: Residential Building; BD+C: Building Design and Construction).

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