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Health benefits of evidence-based biophilic-designed environments: A review

Shih-Han Hung[1] and Chun-Yen Chang[2*]

[1]Doctoral student, Department of Horticulture and Landscape Architecture, National Taiwan University, Taiwan
[2]Professor, Department of Horticulture and Landscape Architecture, National Taiwan University, Taiwan

ABSTRACT

Background and objective: People-nature experiences, which suggest that humans seek connections between nature and other forms of life, were presented by biologist E. O. Wilson in 1984. Biophilic design attributes support environments that can improve human connections to nature. A significant amount of literature on environmental psychology provides empirical evidence that nature benefits humans, and that practical landscape and built environments can be designed to link humans and nature (e.g., the 14 biophilic design patterns). To date, however, there has been no well-done research on reviewing the health benefits of biophilic design.

Methods: The paper provides a narrative review on biophilic design and human health. The scope of this article is limited to biophilic-design books and peer-review articles related to "biophilic design," "evidence-based," "benefits," "health," rather than an attempt to identify universal issues with biophilia hypothesis.

Results: A total of 45 papers were included in our review, which was related to the top five biophilic design patterns and design: the presence of natural images, the presence of plants, visual and non-visual connections to nature, and material connection with nature. These studies were related to physiology and psychology through direct or indirect connections with nature and experiences in space and place.

Conclusion: This study presents two important comparisons of the empirical research on biophilic design and human health that can explain the relationship of people-nature experiences to biophilic design and human health and provides insights into related researches and recommendations for future application of our findings.

Keywords: Biophilic design, urban green spaces, people-nature experiences, individual health benefits

Introduction

When the COVID-19 pandemic spread worldwide, thousands of people were forced to stay indoors more than usual. Even though research has shown that 120 minutes of contact with nature every week increases health and well-being (White et al., 2019), this phenomenon has significantly affected people's lifestyles; some of these changes include working from home and social distancing in public, each of which reduces opportunities to experience nature. A study by Lopez et al. (2020) described the critical social use of urban parks before and during the COVID-19 crisis: when one worried about social distancing, crowding, safety, accessibility, etc., it affects one's willingness to visit parks/green spaces. However, research pointed out the increasing number of people start to visit greens even more than before COVID-19. Overall, people consider parks and green spaces, especially the elements of trails, trees, shading, seating, landscaping, and water, to be integral for physical and mental health (Lopez et al., 2020). Despite these recent changes, being in nature can be seen as a beneficial resource for health issues and the human ecology system, which enhances numerous physical and mental health benefits.

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First author: Shih-Han Hung, shellyhung6327@gmail.com, https://orcid.org/0000-0002-2937-4255
***Corresponding author:** Chun-Yen Chang, cucmail@ntu.edu.tw, https://orcid.org/0000-0001-6244-1977

Humans live in the ecosystem and are part of the biosphere, so unsurprisingly, their emotions are closely connected to nature. Humans prefer savanna-like landscapes and positive attitudes that lead them to immerse themselves in nature (Balling and Falk, 1982; Heerwagen et al., 1993). In Biophilia Hypothesis, Wilson (1984) described humans as being deeply connected to nature and lifelike elements. Joye and De Block (2011) further asserted that different genetic predispositions influence biophilic tendencies. Several environmental psychology studies have been conducted into the contributions of nature verse urban areas that support attention restoration, positive emotions, reduced stress, and other physical benefits (Berto, 2005; Barton and Pretty, 2010; Hartig et al., 1991; Kaplan and Kaplan, 1989; Ulrich, 1981; Kim et al, 2016; Marcus and Sachs, 2013; White et al., 2019). Kellert (2018) pointed out human adaptations and design applications that focus on the use of biophilic design attributes, which are included in a built environment to improve the connection to nature, provide health benefits (Browning et al., 2014; Berto et al., 2015). These designs are inspired by natural patterns, attributes, and elements and encourage the use of these features and systems in a built environment to provide humans with the health benefits of a much-needed exposure to nature.

While the literature is replete with discussions related to biophilia and biophilic designs that relate to human health, an analysis of the relationship between nature and health is still lacking. As such, this study will address the following questions: What is a biophilic design, and what is the relationship between biophilic design and health outcomes? In the present study, we will review and evaluate several evidence-based studies and describe the critical role of landscape designers in our everyday contact with nature.

Research Methods

The goal was to build an evidence-based review of biophilic design and the health benefits thereof according to the broad concept described in 14 Patterns of Biophilic Design (Browning et al., 2014) and the elements presented in Nature by Design: The Practice of Biophilic Design (Kellert, 2018). Based on those descriptions, we included biophilic design as the variation of a direct and an indirect connection to nature and of a space and place with the health-benefit outcomes of "psychological health" and "physiological health," as all of these describe the relationship between biophilic design and human health. The "cognitive" focuses on cognition and behavioral performance, including concentrating, communication, productivity, etc.; the "psychological health" includes positive emotion, tranquility, relax, low anger, environmental psychological sense of feelings, etc.; the "physiological health" is about low physical tension, such as lower heart rate, blood pressure, pain, etc. However, the "cognitive" outcomes are part of the psychological feeling, in this article, we connect and integrate those into "psychological health", which could be more consistent with the study.

Search and selecting articles

Based on the core concept of biophilic design (Kellert et al., 2008; Kellert, 2018), this study is a narrative review of disparate literature that describes known health benefits related to biophilic design. The keywords "biophilic design," "evidence-based," "benefits," and "health" were searched on Google Scholar; and 10 relevant studies, review articles, reports, and books were selected to interpret the concept of biophilic design and the relationship thereof to human health and well-being (i.e., Browning et al., 2014; Gillis and Gatersleben, 2015; Grinde and Patil, 2009; Gullone, 2000; Heerwagen and Hase, 2001; Heerwagen, 2006; Kellert et al., 2008; Kellert, 2018; Lumber et al., 2018; Ryan et al., 2014). The snowballing method was then used to further enlarge the body of related articles, particularly those published in SCI, SSCI, A&HCI journals, etc. A total of 62 articles were chosen; repeated articles, review articles, and irrelative content were excluded, resulting in 45 articles for the next step of the analysis, see Fig. 1. A majority of these papers were from the *Journal of Environmental Psychology* and *Environment and Behavior*; and some were from the *International Journal of Environmental Research and Public Health*, *HortTechnology*, and *Health & Place*, etc., among others. The experiments conducted in these studies typically involved the use of photographs,

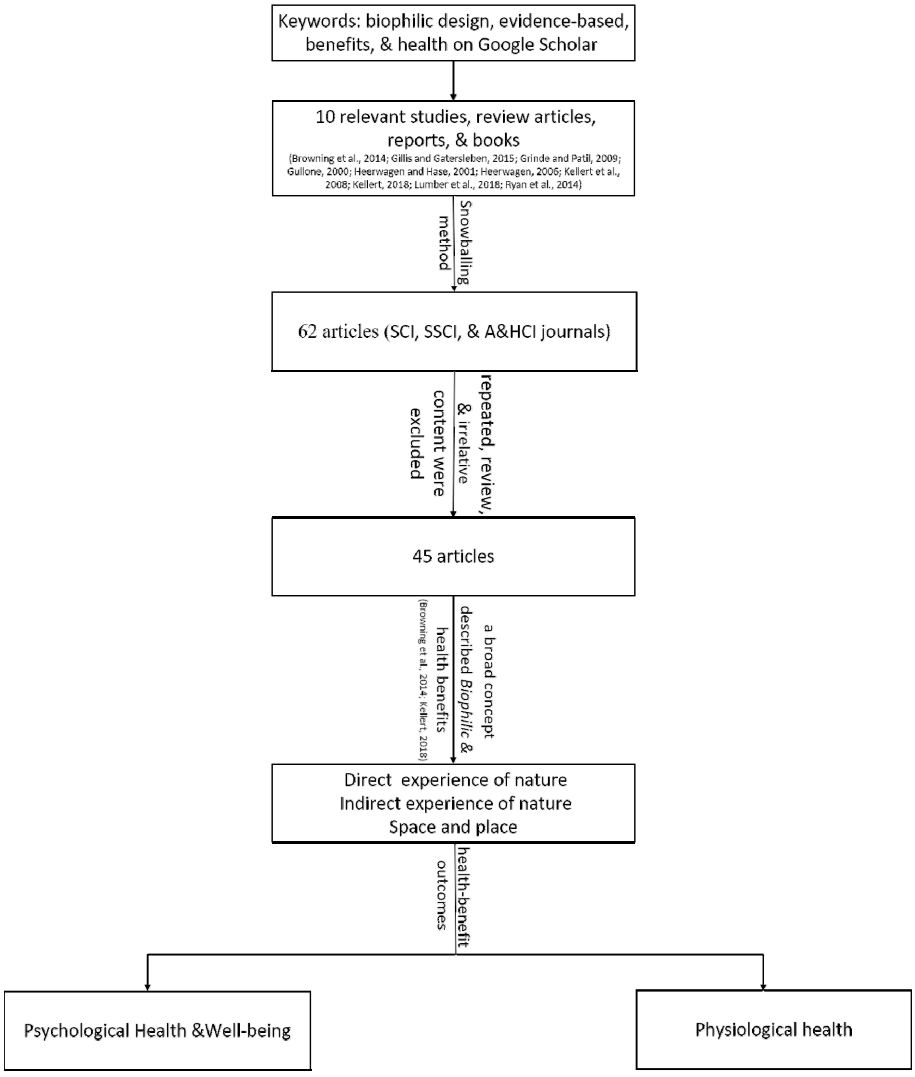

Fig. 1. The flow chart about searching and selecting method.

videos, direct contact with natural and/or urban environments, laboratories, and workplaces; and they utilized a quantitative or qualitative method, including the use of preference questionnaires, the Perceived Restorativeness Scale (PRS), a Profile of Mood States (POMS), Zuckerman Inventory of Personal Reactions (ZIPPER), biofeedback, and functional Magnetic Resonance Imaging (fMRI) to measure the health benefits and brain activities of biophilic designs.

The biophilic design patterns include visual and non-visual connections to nature; non-rhythmic sensory stimuli; thermal and airflow variability; the presence of water, plants, or animals; biomorphic forms and patterns; materials that are connected to nature; complexity and order; the concept of prospect and refuge; the risks and perils; and mystery (Browning et al., 2014). The elements considered were light, air, plants, animals, water, views, landscapes, weather, shapes and forms, materials, textures, colors, images, organized and complexity, prospect and refuge, etc., were integrated with similar concepts into new categories of biophilic design patterns and elements (Table 1); for example, "visual connection to nature" is related to "view" and "landscape," so these were combined into one biophilic pattern.

Data analysis

The relationships between different natural patterns and elements and health benefits that were described in the lit-

Table 1. Description of selected biophilic design patterns and elements

Different Experiences with Nature	Biophilic Design Patterns and Elements	Brief descriptions refer to Browning et al. (2014) and Kellert (2018)
Direct experience with nature (i.e., nature in the space)	Visual connection to nature	Window views/landscapes; physically being in nature
	Non-visual connection to nature	Auditory, haptic, olfactory, or gustatory connection to nature
	Non-rhythmic sensory stimuli	Stochastic and ephemeral connections to nature with unanticipated stimuli
	Thermal and airflow variability	Weather (e.g., the wind), air temperature, airflow, and air quality can be felt
	Presence of water	Water elements are placed in interior/exterior areas
	Presence of plants	Plants are placed in interior/exterior areas
	Presence of animals	Birds, fish, etc. are placed in the environment
	Dynamic and diffuse light	Place connects to natural light and shadows or is affected by the changeability of seasons; includes windows in the workplace
Indirect experience with nature (i.e., natural analogues)	Biomorphic forms and patterns	Natural geometries, shapes, forms, and biomimicry styles
	Materials connected to nature	Use of colors, textures, and materials
	Presence of nature images	Photos or painting of nature (e.g., water, waterfall, forest, mountain, etc.), especially in the workplace, schools, or hospitals
	Simulated natural light and air	Use of artificial lighting to mimic a sense of natural light
Space and place (i.e., nature of the space)	Prospect and refuge	Seeking to satisfy an innate desire to have the opportunity (i.e., prospect) to review a space while feeling safe (i.e., refuge) (Appleton, 1975)
	Organized/complexity	Rich in detail and diversity with the organization; uniform and featureless without being boring (e.g., fractal geometries in nature, art, architecture)
	Mobility and transitional spaces	Moving from one place to another place (e.g., paths, walks); links the interior to the exterior; fosters emotional and aesthetic appeal
	Place	Identifying the place
	Integrating parts to create a whole	Connecting with natural systems and ecosystem; includes awareness of change, age, and the patina of time in the environment; coherence in the environment
	Risk/peril/mystery	Arouses attention and curiosity, refreshes memory, improves problem-solving skills

erature and the experimental stimuli were analyzed to classify the environment into different biophilic patterns and elements. We then used Microsoft Excel (Office 2016) to integrate the results into one of the following categories: psychological health and well-being and physiological health.

Descriptive analysis of biophilic patterns and elements

A total of 45 peer-reviewed studies that re-examined the interactions between the environment and human health benefits were selected. Of the proposed biophilic design patterns and elements, we determined that "the presence of natural images" (24%), "the presence of plants" (14%), "non-visual connections to nature" (13%), and "visual connections to nature" (11%) and, "material connection with nature" (11%) etc. were the most frequently used in experimental research designs and related health benefits (Fig. 2).

Content analysis of the 45 articles

A brief description of the content analysis showed in Table 2. According to the contents, we found out there were 43 articles tested about the psychological outcomes by using the patterns of "direct and indirect experience of nature" and "space and place". The psychological outcomes include increasing productivity, creativity, concentration, attention restoration, positive mood, lower tension, and anxiety, etc. Eighteen articles tested the physical index with the biophilic patterns, such as low heart rate, pain, decrease diastolic blood pressure (DBP), systolic blood pressure (SBP), skin conductance, etc. Besides, we found out the researchers would evaluate several health benefits or the similar concepts use a different method to test, for example, "stress" could be tested in the questionnaire or physical stress (i.e. DBP or SBP, etc.). Therefore, there were sixteen

articles both discuss the psychological and physical outcomes. We would categorize those benefits into both labels in psychological and physical outcomes.

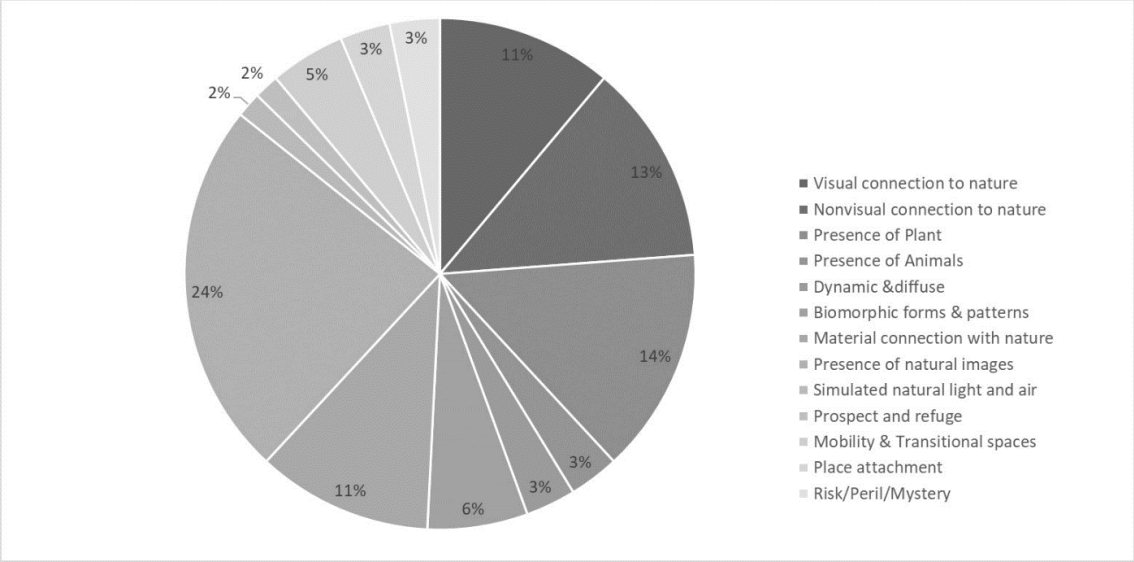

Fig. 2. Proportions of different patterns in biophilic design.

Table 2. A brief description of content analysis of 62 articles about the psychological and physical outcomes

	Selected	Brief Content Analysis	Reference
1	V	nursing / hospital / windows / light / psychological / physical	Zadeh et al., 2014
2	V	children / school / windows / light / psychological / physical	Küller & Lindsten, 1992
3	V	individual / viewing photos-urban & natural landscape + sound / psychological / physical	Ulrich et al., 1991
4	V	students & staff / viewing photos- water features, green spaces, buildings, animals, plants, people / psychological	White et al., 2010
5	V	student / sound-nature urban environmental sound / psychological / physical	Alvarsson et al., 2010
6	V	individual / office space/ real potted plants / psychological	Larsen et al., 1998
7	V	staff / real office design / planting / psychological	Nieuwenhuis et al., 2014
8	V	individual / real potted plants / physical	Qin et al., 2014
9	V	individual / viewing photos-city, nature, weather type, bright / psychological	Beute & de Kort, 2013
10	V	concept* / psychological	Kaplan, 1995
11	V	patient / hospital / window viewings with or without plants / psychological / physical	Ulrich, 1984
12	V	students / indoor-window view / natural photos / psychological	Felsten, 2009
13	V	residents / simulation photos / psychological	White & Gatersleben, 2011
14	V	students / viewing photos-urban roof & simulation ones / psychological	Lee et al., 2015
15	V	students / real nature and urban environment-walking & sidewalk / psychological / physical	Hartig et al., 2003
16	V	participants in school / video-urban & forest trail with/without water+ sound / psychological / physical	Van den Berg et al., 2003
17	V	participants in school / photos-beach, highway/ psychological / physical	Hunter et al., 2010
18	V	students & school staffs / viewing photos- urban, country, sea, etc. + voice / psychological	Pheasant et al., 2010
19	X	review articles	Velarde et al., 2007
20	X	repeated articles in 10 main list	Kellert, 2018

Table 2. (continued)

	Selected	Brief Content Analysis	Reference
21	V	office employees / indoor plants / psychological	Bringslimark et al., 2007
22	V	staffs / real office design/plantings / psychological	Shoemaker et al., 1993
23	V	students / scenario of hospital plantings & city map / psychological	Dijkstra et al., 2008
24	V	students / simulated office photos-plants / psychological / physical	Chang & Chen, 2005
25	X	review articles	Browning et al., 2014
26	V	muti-analysis of researches / psychological	Barton, & Pretty, 2010
27	V	school staffs / nature & urban photos / psychological / physical	Brown et al., 2013
28	X	review articles	Van den Berg et al., 2007
29	V	participants in school / real space simulation office / river sound / noise / physical	Jahncke et al., 2011
30	V	college students / touch real plants / psychological / physical	Koga & Iwasaki, 2013
31	V	consumers / real fish tank / behavior analysis / psychological	Windhager et al., 2011
32	X	repeated articles	Hartig et al., 2003
33	V	elderlies / local park / psychological / physical	Orsega-Smith et al., 2004
34	X	repeated articles in 10 main list	Lumber et al., 2018
35	V	concept* / psychological	Schatz & Bowers 2005
36	X	review articles	Edwards & Torcellini, 2002
37	X	review articles	Fitzgerald & Danner, 2012
38	V	students / performance / daylight / psychological	Nicklas & Bailey, 1996
39	X	repeated articles in 10 main list	Kellert et al., 2008
40	X	repeated articles	Bringslimark et al., 2007
41	V	residents / qualitative research / sound- birds, natural sound / psychological	Ratcliffe et al., 2013
42	V	staffs / simulating real office environment / plantings / psychological	Knight & Haslam, 2010
43	V	clinic / nature park / video / psychological / physical	Kjellgren & Buhrkall, 2010
44	V	students/ simulated wood ratio / psychological /physical	Tsunetsugu et al., 2007
45	V	nursing / hospital / photos- wood / psychological	Nyrud et al., 2014
46	V	individuals / color (green, red, gray, etc.) / psychological	Lichtenfeld et al., 2012
47	V	individuals / fractal dimension / computer model / psychological	Hagerhall et al., 2004
48	V	concept* / psychological	Joye, 2007
49	V	individual / photos, walking / psychological / physical	Gatersleben & Andrews, 2013
50	X	irrelative content/development scale	Grahn & Stigsdotter, 2010
51	V	students / photos-forest / psychological	Herzog & Bryce, 2007
52	X	book	Salingaros, 2017
53	V	residents / online questionnaires / favorite places / psychological	Korpela et al., 2009
54	X	irrelative content / description the relationship between favorite places and restorative, but hard to categorize into biophilic elements and patterns	Korpela et al., 2001
55	V	students / photos-forest / psychological	Herzog & Kropscott, 2004
56	X	irrelative content/focus on the activity types in physical and social situation to predict perceived danger, tension, and fear	Rapee, 1997
57	V	individual / content analysis /positive & negative emotions / natural scenes / psychological	Van den Berg & Ter Heijne, 2005
58	X	irrelative content	Mehta et al., 2012
59	X	review articles	Tsunetsugu et al., 2010
60	V	concept* / psychological / physical	Reddy et al., 2012
61	X	repeated articles	Qin et al., 2014
62	V	staffs / real-like office / plantings / interview / psychological	Thomsen et al., 2011

Results and Discussion

Health benefits of biophilic patterns: Psychological health and well-being

Table 3 shows the psychological health and well-being outcomes of biophilic designs, including but not limited to feeling positive emotions and pleasure, attention restoration, preference, feelings of relaxation, and decrease a sense of anger, etc. Moreover, it includes increasing cognitive functionality and performance.

Several studies found that visual and non-visual connections to nature and direct experiences with nature that is made possible by the presence of plants have positively affect psychological health and well-being in outdoor environments and interior designs (e.g., Barton and Pretty, 2010; Hartig et al., 2003; Larsen et al., 1998; Orsega-Smith et al., 2004; Pheasant et al., 2010; Thomsen et al., 2011); those results are in line with two environmental psychological theories－Attention Restoration Theory (Kaplan and Kaplan, 1989) and the Stress Reduction Theory (Ulrich et al., 1991), which explain two ways in which contact with nature improves people's psychological states; the presence of plants in an office also reduces perceived stress (Dijkstra et al., 2008; Larsen et al., 1998). Moreover, in an office setting and a hospital, exposure to nature and sunlight through a window view can improve employee performance and mood (Zadeh et al., 2014); and patients are able to recover better from surgery (Ulrich, 1984). Besides, much of the literature described how a visual connection to nature and the presence of plants in an outdoor/indoor environment, also referred to as "direct experience with nature," can improve cognitive functionality and performance by increasing communication, concentration, and productivity, (e.g., Shoemaker et al., 1992; Thomsen et al., 2011; Larsen et al., 1998; Zadeh et al., 2004). One of the cited studies highlighted that being physically present in nature not only could stimulate sensory perceptions and feelings of well-being, but also alters states-of-consciousness, especially feelings of relaxation (Kjellgren and Buhrkall, 2010).

However, these studies yielded few findings between the psychological impact of indirect experiences with nature, such as biomorphic forms and patterns, materials, and natural images that could enhance creativity and productivity (Joye, 2007; Lichtenfeld et al., 2012). Schatz and Bowers (2005) investigated how color design in the workplace influences worker moods, performance, productivity, and satisfaction. Tsunetsugu et al. (2007) discovered that an interior that is composed of 45% wood imbues a sense of comfort, naturalness, and restfulness; these results are similar to those of a study that incorporated natural elements in a hospital setting (Nyrud et al., 2014).

"Space and Place" is defined as the nature of the space. Visual connections to nature and exposure to natural environments with high prospect levels and low refuge levels are restorative; alternately, exposure to natural environments with low prospect levels and high refuge levels aren't restorative, however, could increase negative emotion, physical stress, and attention fatigue (Gatersleben and Andrews, 2013). Whether in the field of in laboratory experiments, the feeling of being connected to nature in a naturally designed setting, as opposed to an urban setting, has been shown to markedly improve psychological health and well-being by affecting pleasure and emotion, restoring attention, and reducing stress (Browning et al., 2014; Hartig et al., 2003; Ryan et al., 2014; White et al., 2010); furthermore, a natural-setting space can evoke a sense of mystery, attraction, and one's preference (Herzog and Bryce, 2007; Herzog and Kropscott, 2004). Rapee (1997) found, however, that perceived threats in nature-based activities, such as on a mountain, in an alley or forest, or while scuba diving, can lead to feelings of anxiety and fear.

Biophilic patterns: Physiological health benefits

Table 4 shows the physiological effects that were identified using instruments to detect heart rate, blood pressure, cortisol levels, and other physiological indicators, in addition to a questionnaire intended to understand stress reactions in the human body. These findings were similar to those for psychological health and well-being: Visual and non-visual connections to nature and the presence of plants and light reduces stress, lowers the heart rate, and decreases blood pressure, among other benefits (Hartig et al., 2003; Küller and Lindsten, 1992; Ulrich, 1984; Ulrich

Table 3. Biophilic patterns and psychological health and well-being.

	Direct experience of nature					Indirect experience of nature				Space and place			
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms & patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
Promoting Attention restoration	2	1 & 2		1			1	3		2	2		
Appeal aesthetic /attraction/interesting		2	2			1		2			2		
Preferences		1 & 2	2	1		1 & 2	1 & 2	3			2		2
Positively impacted attitude/Positive affects/ pleasure arousal	2	2				1	1	3		2	2		
Positive emotion/mood responses	2	1	2	1			1						
Negative mood	2							2					
Induce tranquility		2						2					
Feel relax/Restoration			2	1			2						
Low sense of fear/ Perceived fear		1 & 2						2		2			
Low anger aggression	2	2					1	2		2	2		
Low tension	2										2		
Low anxiety/stress	2	2	2	1			1 & 2	2			2		
Low depression/Sadness	2	1 & 2						2			2		
Perceived of danger	2							2		2			2
Pleasure		2					2						
effortless attention		1		1									
Psychological health		1	2						1				

Table 3. (continued)

	Direct experience of nature					Indirect experience of nature				Space and place			
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms & patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
Overall happiness	2	2						2			2		
Familiarity	2	2									2		
Complexity								2			2		2
Fascination	1 & 2	1		1				2			2		
Being away	1 & 2							2					
Extent	1 & 2							2					
Compatibility	1 & 2							2			2		
Mystery				1		1 & 2							
Legibility						1 & 2							
Coherence													2
place attachment												2	
Improve mental engagement attentiveness								2		2			
Positive impact on cognitive performance					2		1		1				
Increase productivity			2				1		2				
Enhanced creativity							2						
Improve communication	2												
Concentration			2		2								
Social interaction	2												
Decrease sleepiness	2												
Decrease sick leave			2										

Table 3. (continued)

	Direct experience of nature					Indirect experience of nature				Space and place		
	Visual connection to nature (Barton & Pretty, 2010; Felsten, 2009; Hartig et al., 2003; Orsega-Smith et al., 2004; Ulrich, 1984; Van den Berg & Ter Heijne, 2005; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Koga & Iwasaki, 2013; Pheasant et al., 2010; Ratcliffe et al., 2013; Ulrich et al., 1991; Van den Berg et al., 2003)	Presence of Plant (Bringslimark et al., 2007; Dijkstra et al., 2008; Knight & Haslam, 2010; Larsen et al., 1998; Nieuwenhuis et al., 2014; Qin et al., 2014; Shoemaker et al., 1992; Thomsen et al., 2011)	Presence of Animals (Ratcliffe et al., 2013; Windhager et al., 2011)	Dynamic &diffuse light/season (Küller & Lindsten, 1992; Nicklas & Bailey, 1996)	Biomorphic forms & patterns (Hagerhall et al., 2004; Herzog & Bryce. 2007; Herzog & Kropscott, 2004; Joye, 2007)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Lichtenfeld et al., 2012; Nyrud et al., 2014; Schatz & Bowers, 2005; Tsunetsugu et al., 2007; Reddy et al., 2012)	Presence of natural images (Beute & de Kort, 2013; Brown et al., 2013; Chang & Chen, 2005; Felsten, 2009; Herzog, & Kropscott, 2004; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Lee et al, 2015; Nyrud et al., 2014; Pheasant et al., 2010; Ulrich et al., 1991; White et al., 2010; White & Gatersleben, 2011; Van den Berg et al., 2003)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Beute & de Kort, 2013; Hartig et al., 2003; Van den Berg et al., 2003)	Place (Küller & Lindsten, 1992; Korpela et al., 2009)	Risk/Peril (Herzog & Kropscott, 2004; Herzog & Bryce, 2007)
State of consciousness								2					
Satisfaction (job, workplace)			2				1						
Self-esteem	2							2					
Motivation							1						
Self-confidence			2										

Note. 1 = Indicates a relationship between the biophilic patterns, even though outcomes are not yet directly supported by empirical studies; these may be influenced by biophilic patterns.
2 = Indicates a relationship between biophilic patterns and outcomes that is supported by empirical studies (< 5 papers).
3 = Indicates strong evidence of a relationship between biophilic patterns and outcomes and significant results from multiple types of research (≥ 5 papers).
An empty cell indicates that a relationship between the biophilic patterns and the outcome has not yet been determined.

Table 4. Biophilic patterns and physiological health

	Direct experience of nature				Indirect experience of nature			Space and place	
	Visual connection to nature (Hartig et al., 2003; Orsega-Smith et al., 2004; Zadeh et al., 2014)	Nonvisual connection to nature (Alvarsson et al., 2010; Jahncke et al., 2011; Reddy et al., 2012; Ulrich et al., 1991)	Presence of Plant (Qin et al., 2014; Thomsen et al., 2011; Ulrich, 1984)	Dynamic &diffuse light/season (Küller & Lindsten, 1992)	Material connection with nature (Joye, 2007; Koga & Iwasaki, 2013; Tsunetsugu et al., 2007)	Presence of natural images (Brown et al., 2013; Chang & Chen, 2005; Hunter et al., 2010; Kjellgren & Buhrkall, 2010; Tsunetsugu et al., 2007; Ulrich et al., 1991)	Simulated natural light and air (Reddy et al., 2012)	Prospect and refuge (Gatersleben & Andrews, 2013)	Mobility & Transitional spaces (Van den Berg et al., 2003)
Low blood pressure					2	2			
Low heart rate (BVP)	2					2		2	
SDRR						2			
Decrease in diastolic blood pressure (DBP)	2				2	2			2
Decrease in systolic blood pressure (SBP)	2				2	2			2
Frontalis muscle tension (EMG)		2				2			
Electroencephalogram (EEG)			2			2			
Less pain						2			
Reduce skin conductance level(SCL)	2	2							
Gain energy						2			
overall (Perceived) physical health	2	2	2				1		
Brain activity						1&2			
Body temperature	2								
Blood oxygen	2								
Cortisol				2					
Pulse transit time(PTT)		2		2					
Oxyhaemoglobin				2	2				

Note. 1 = Indicates a relationship between the biophilic patterns, even though outcomes are not yet directly supported by empirical studies; these may be influenced by biophilic patterns.
2 = Indicates a relationship between biophilic patterns and outcomes that is supported by empirical studies (< 5 papers).
An empty cell indicates that a relationship between the biophilic patterns and the outcome has not yet been determined.

et al., 1991; Zadeh et al., 2014). Moreover, Pheasant et al. (2010) indicated that the perceived stimulation from the environment and the visual-auditory interactions thereof can affect a sense of tranquility; this is in line with Hunter et al. (2010), who found out that, compared to viewing a freeway, viewing a beach influences a stronger sense of tranquility and activates the connection between the auditory and perception areas in the brain. Tsunetsugu et al. (2007) also concluded that the use of natural analogs, such as natural materials, can lead to stress reduction.

Conclusion

This review collected and integrated the 18 patterns of biophilic design with the 18 physiological health outcomes and 42 psychological outcomes, including 14 cognitive functionality and performance; and concluded that most of the cited research used natural images (e.g., mountains, forests, water elements), the presence of plants in an interior environment, and a visual connection to nature in an indoor environment as methods to investigate the relationship between nature and human health. Moreover, some studies used non-visual nature connections such as natural sounds or textures to determine benefits with nature. These studies were selected because they present evidence-based conclusions that natural patterns and elements, which are associated with biophilic design principles that support human adaptation, engagement, and immersion in nature, improve human health and provide multiple benefits for humans in a built environment (e.g., increase productivity and provide aesthetic appeal, emotional attachment, and physical and social dimensions) (Kellert, 2018).

Five patterns were determined to limit the findings in

this study: non-rhythmic sensory stimuli, thermal and airflow variability, the presence of water, organized/complexity, and integrating parts to create a whole. The empty cells in Table 2-4 indicate a possible direction for researchers who wish to test these relationships; for example, Kellert (2018) explained that direct or indirect connections to water, such as pictures and videos of wetlands, ponds, and waterfalls, provides human-nature experiences and the psychological and physiological benefits thereof. White et al. (2010) also asserted that photographs of water, plants, animals, and other elements of nature can influence a person's preferences, affections, and levels of restorativeness, which can lead to further research to investigate the benefits of actual exposure to landscapes and water to psychological and physiological health. Patterns of thermal and airflow variability are associated with weather and good atmospheric conditions, which is linked to human-nature experiences (Browning et al., 2014; Kellert, 2018); future studies could shed light on the micro-climate indicators in a built environment that influence human feelings. Finally, the different forms of landscapes (e.g., English, French, Japanese, and Chinese gardens), the organization and complexity thereof, and the pattern of integrating parts of those landscape patterns to create a whole that can affect human health warrants further investigation.

The concept of biophilia is a psychological feeling of connecting nature and humans; the biophilic design is a method of using nature and natural-like patterns and elements that enhance the opportunity for humans to exposure to nature in the built environment. It can be used to construct a framework a people-nature experiences, to verify the impact that these biophilic patterns have on human physiological and psychological health in urban green spaces. More specifically, the research found out the 18 patterns and elements of biophilic design and health could be widely used in visual and non-visual connections to nature, the presence of natural images, natural material, and plants in outdoor or interior environment, which could reduce psychological and physical stress, recover attention restoration, and improve positive emotion and aesthetic attraction, etc. Those findings are related to the concept of restorativeness environment (i.e. being away, fascination, extent, and compatibility), landscape preference (i.e. legibility, mystery, complexity, coherence), and the stress reduction theory. By better understanding, these relationships and the related theories in environmental psychology, the methods that incorporate biophilic design measures to improve the landscapes and urban designs can be devised.

Our findings as using the biophilic patterns and elements might be linked to the Sustainable Development Goals (SDGs) of Goal 3 for the action of "ensuring healthy lives and promoting well-being", Goal 11 for "making cities and human settlements inclusive, safe, resilient and sustainable", and Goal 15 for "protecting, restoring and promoting sustainable of ecosystems on land". Those policies are insights to link biophilic design as an approach of restorativeness and ecological environment for balancing human and species in the built environment.

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