A review of biophilic design conception implementation in architecture

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This review is about biophilic design and architecture, definitions, implications and application. Scan books and studies have illustrated that the existence of terms 'Biophilic' and 'Architecture' in tandem is dramatically low, and it seems that there is no commonly agreed definition of biophilic architecture among researchers and professionals. Therefore, it has attempted to refine the concept of biophilic design in architecture, and clarifying ambiguities. The authors employed a systematic literature review methodology to synthesize research. The search results included 112 studies in the past 35 years (1984 – March 2020). Finally, 45 papers and books on the biophilic architecture were evaluated and analyzed accurately based on the leading purpose of this review study. Biophilic architecture(BA) inherently seeks to establish a reconnection between human beings and nature, and its main purpose is to promote human health and well-being. Implementation of BA should be done according to 14 biophilic design patterns and the Kellert framework. However, more research is needed to discover and develop the underlying aspects of the definition of BA, such as the need for environmental health and to meet the needs of the human's evolutionary dimensions, which is the main distinguishing feature of this approach.

Keywords: *Biophilic design, Biophilic architecture, Health and well-being, Nature.*

1. INTRODUCTION

Urban communities now suffer from various physical and psychological disorders. Many studies show that it is because of the current design and construction methods which result in ruinous separation from nature. According to the bulk of studies regarding the correlation between human health and experiences in nature, human connection with nature can leave significant impacts on people's overall health and well-being. (Hartig et al. 2010, Bowler et al. 2010, Brymer et al. 2010, Bratman et al. 2012, Keniger et al. 2013, Hartig et al. 2014, Bratman et al. 2015, Frumkin et al. 2017) Unfortunately, human beings have been separated from nature by the modern civilization culture. This pernicious way of environmental design compels researchers and architects to seek a new design approach which can enliven the contemporary environmental design and architecture. Primarily mentioned in Heerwagen's publications (Heerwagen J.H. 1998, Heerwagen J.H, Hase B. 2001), the biophilic conception is a novel approach introduced in the 21st century. Herman Miller coined the term "phylogenetic design" to refer to the design based on the perception of an evolved relationship between people and nature. (Heerwagen J.H, Hase B. 2001, 5) Promoting the biophilic notion in design and architecture, Kellert argued that a low environmental impact design approach per se would fail to achieve sustainable development in the long run and that "positive environmental impacts" — or what he later called the "biophilic design" — was required for the long-term sustainability. (Kellert. 2004) According to Kellert, the biophilic design(BD) is defined as "the deliberate attempt at translating an understanding of biophilia into the design of a built environment" (Kellert et al., 2008, 3); however, how can it be implemented in architecture? Kellert asserted, "The BD is not about greening our buildings or simply increasing their aesthetic appeal by inserting trees and shrubs. More importantly, it is about humanity's place in nature and the natural world's place in human society." (Kellert et al., 2008, vii) Although there must be greenery in buildings for therapeutic aspects, the building structure itself must also be healing. (Salingaros N.A. 2015) However, architects have sometimes misused the term biophilia to support only the "green" aspects of a design. Apparently, the accurate perception of BD in architecture is still unclear and incomplete. This review analyzes the previous attempts at explaining BD with a focus on biophilic architecture(BA). The paper argues that most of the studies describing BA refer to Kellert's BD definition and that there are only a few different interoperations of BA The absence of a precise definition of BA can lead to misconception and false implementation, which would limit the development of biophilic buildings.

2. MATERIALS AND METHOD

Addressing the literature on BA thoroughly, this paper reviews nearly all of the existing papers and books regarding BD in the past 35 years (1984 – March 2020). The term "biophilic" per se and also accompanied by "design, architecture, or building" were searched for in titles of papers in Web of Science, Scopus, and ScienceDirect databases. The search results included 112 studies of different types such as journals, book reviews, conference papers, and reports. Abstracts and conclusions were analyzed in the first stage of the literature review. The resultant information showed that seven papers were mainly about biophilia hypothesis, whereas seven other papers were about BD and ethics. Accordingly, 98 papers were selected in direct relation to BD. As the thematic diagram (Figure 1) indicates, the existing materials were classified as different categories in terms of their main topics. At first, 19 books and papers on the BD theory were reviewed in total, whereas 45 papers and books on the BA were then evaluated and analyzed accurately based on the leading purpose of this review study.

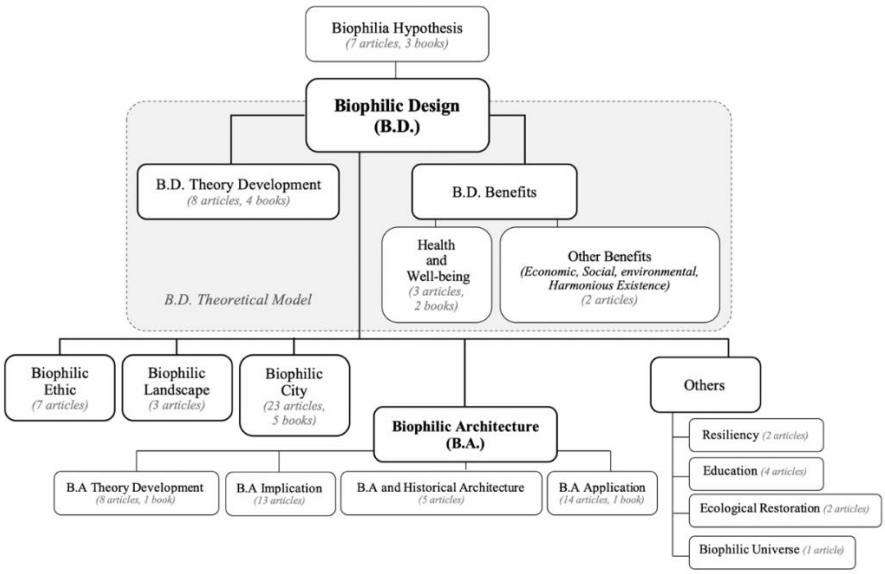
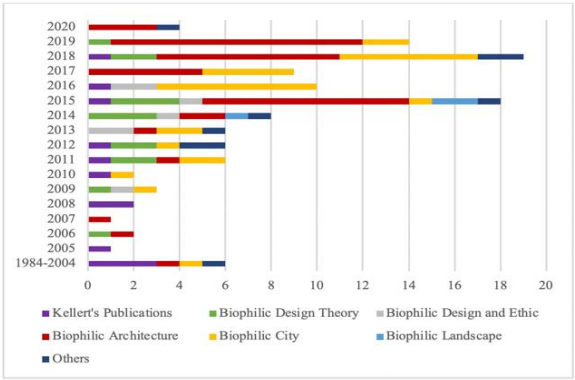
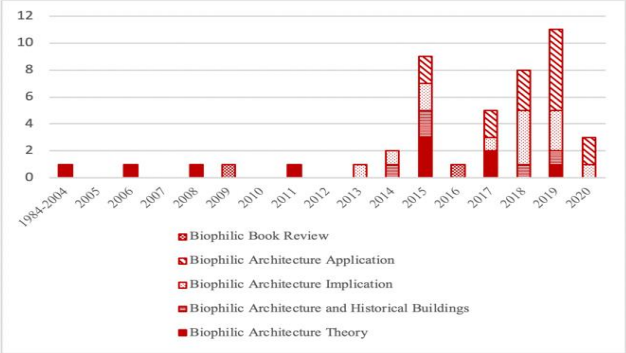


Figure 1: Thematic diagram of Biophilic design's publications from 1984 to 2020(March)

Although the BA has been discussed in only 35% of all books and studies in the field of BD, relevant research has been proliferating in the last six years. This emphasizes the importance of the subject (Graph 1). Furthermore, 82% of the papers on the BA were written in the last six years. There is only 16% of studies which developed the BA theory, whereas most of the papers (38%) explored the functional and practical frameworks and solutions for the BA However, the other major group of papers (32%) analyzed the practical impacts of the BA on human beings empirically (Graph 2). The increasing trend in the BA implementation and relevant implications would now show the precedence of this topic as well as the need for its enlightenment that has formed the main focus of this review study.



Graph 1: Number of biophilic design publications in each year



Graph 2: Number of biophilic architecture publications in each year, from 1984-2020(March) from 1984-2020(March)

3. BIOPHILIA HYPOTHESIS

Edward O. Wilson recognized that "human has inherent psychological affinities to the natural world, including aesthetic appreciation, emotional attachment, and spirituality, and all of these affinities have evolutionary and developmental significance." (Knight & Riedel, 2002, p133) In 1984, Wilson defined the Biophilia hypothesis, which is sometimes called the "Psycho-Evolutionary Restoration Theory" (Williams, 2018, p x) as; "the innate tendency to focus on life and lifelike processes." (Wilson, 1984, p1) "This proposition suggests that human identity and personal fulfillment somehow depend on our relationship to nature. The human need for nature is linked not just to the material exploitation of the environment but also the influence of the natural world on our emotional, cognitive, aesthetic, spiritual development, and other values. Even the tendency to avoid, reject, and at times, destroy elements of the natural world can view as an extension of an innate need to relate deeply and intimately with the vast spectrum of life about us." (Wilson & Kellert, 1993, px)

4. BIOPHILIC DESIGN

4.1 Biophilic design definition

BD definition had emerged by Kellert in 2004, and have been developing until now (2020). (Figure 3) Kellert BD's explanations can separate into two main parts; before 2012 and after that. From 2004 to 2011, "Biophilic design" has been equivalent to the expression; "Positive environmental impact" and describes, positive connection to the natural world and restoring beneficial contact between people and nature in places of ecological and cultural meaning and familiarity. (Kellert 2004, Kellert 2005, Kellert 2008b, Kellert 2011) In 2008 he outlined BD as "the deliberate attempt to translate an understanding of biophilia into the design of the built environment." (Kellert 2008a) In part two, from 2012 until 2018, Kellert claimed that; BD in the built environment could be achieved by creating a good habitat for people as a biological organism(animal), in the modern cities and built environment, places where we live, work and reside. (Kellert 2012, Kellert 2015, Kellert 2016, Kellert 2018) As has been shown, the statement of "Creating good habitat for people," is the main manifesto, for putting BD conception into architectural practice for refinement of our current built-environment and cities.

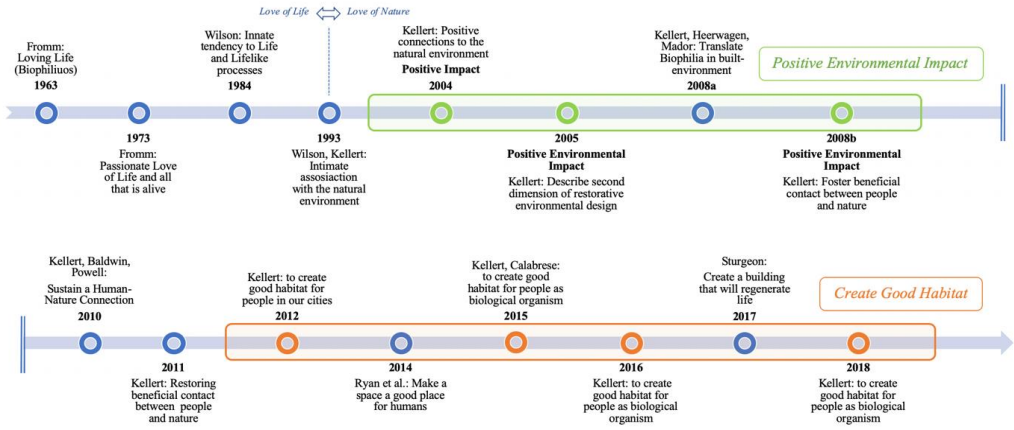


Figure 2 : Timeline of Biophilic Design Interoperation

In addition to Kellert's publications, in 2014, Ryan and colleagues defined BD as; "the codification of human intuition for what makes a space a good place for humans." (Ryan et al. 2014) This definition also has an almost similar meaning to creating a good habitat. Later on, Ryan, with Browning and Clancy, published "14 Patterns of Biophilic Design" to present the relationships between nature, human biology, and the design of the built environment in 3 groups of; nature in the space, natural analogues, and nature of the space. (Browning, Ryan & Clancy. 2014) In 2017, Sturgeon defined BD as; "a conscious discipline that has the potential to reconnect people and nature through buildings intentionally. The opportunity of BD is to connect to the particular ecology of the place, to its culture, history, and beauty and to create a building that will regenerate life." (Sturgeon 2017) All of BD's definitions emphasize on human nature connection and creating a good place for them to live, which states its main definition.

In this BD theoretical model, the concept of a positive connection with nature has been insisted on, since BD, as the second dimension of restorative environmental design, mostly concerns the positive effects of experiencing nature on human. Part 2 declared that the main goal of BD is to promote health and well-being. Also evolutionary root of biophilia hypothesis, (Gullone, 2000) by using of the term productivity with the evolutionary concept of fitness that means "the ability of organisms and species, to survive and reproduce in the environment in which they find themselves", (Orr, 2009, p531) has been emphasized. Last point, expresses the conceptual view to implementation of BD in built environment. (Figure 4)

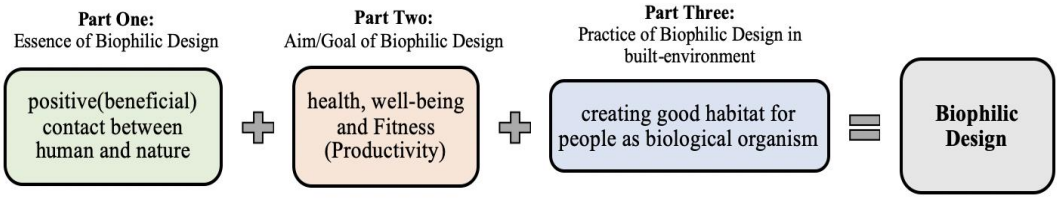


Figure 4: Biophilic Design Theoretical Model

4.2 Biophilic design aim

The key difference between the BD approach and other naturalistic approaches is its goal of promoting human health and well-being, by satisfying human inherent need for nature. So far, the numerous benefits of connection with nature on human holistic health, both individually and in the field of BD, have been extensively researched, and has demonstrated the significant influences of human interaction with nature on human beings' holistic health. (Hartig et al. 2010, Bowler et al. 2010, Brymer et al. 2010, Bratman et al. 2012, Keniger et al. 2013, Hartig et al. 2014, Bratman et al. 2015, Frumkin et al. 2017) World Health Organization (WHO) defined holistic health as; "a state of complete physical, mental, and social

well-being and not merely the absence of disease or infirmity." (Orr, 2009) In 1998, the WHO confirmed the fourth dimension of health as spiritual health. (Svalastog, 2017) So there are four main dimensions for holistic health. Also, Hettler, co-founder of the National Wellness Institute (NWI), developed the six dimensions of the wellness model. This model provides dimensions of wellness that contribute to healthy living. These dimensions are; Physical, Social, Occupational, Intellectual, Spiritual, and Emotional. (Yoong, 2012) Physical, social, and spiritual is the same dimensions in both models. The occupational dimension of wellness "recognizes personal satisfaction and enrichment in one's life through work." (Yoong, 2012) This dimension can categorize as a part of social health. The intellectual dimension refers to mental activities, and it is equal to mental attributes of health. Brain functionality, intellectual performance, and mental activity, more broadly considered in a category of cognitive psychology. Moreover, the emotional dimension integrates with human feelings and mood. These personal affective responses also are parts of emotional psychology. Accordingly, mental and emotional dimensions can classify more comprehensively as the psychological aspect of holistic health. (Figure 5)

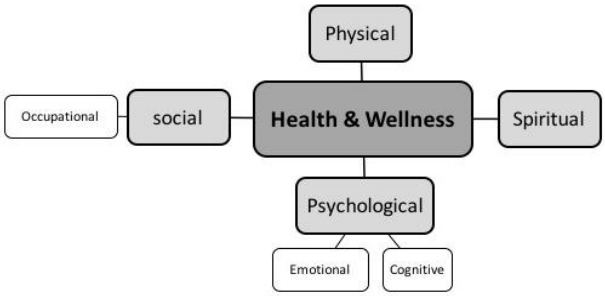


Figure 5: Holistic Health & Wellness Dimensions

4.2.1. *The Human-nature connection impacts on health dimensions*

Some theories explain how human-nature connection can affect human health indicators and some disorders or diseases. The most relevant theories and the considerable impacts on human health briefly explained.

4.2.1.1. *Physical Health*

It encompasses our physical health, the physiological responses of the body, the health of our systems (nerves, muscles, skeleton, heart, etc.), organs (liver, kidneys, lungs, etc.), and our overall physical well-being. (Browning, 2014) Theories related to physical health includes physical activity, immune system, and hygiene hypothesis. Physical activity improves overall human health during their lifetime. (Janssen & LeBlanc, 2010) The human immune system function better in a state of nature connection. Nature killer cells (NK cells) that are a type of white blood cells for fighting with infections and cancers will increase up to 40% in one week of living in nature. (Li et al., 2009, Arvay, 2018) Human physical health indicators impacts by reducing; heart pulse rate, blood pressure, Cortisol level, frontal muscle tension, skin conductance, etc., and increasing; DHEA level, Endomorphin level, (Brymer et al. 2018; Shanahan et al. 2016; Keniger et al. 2013; Soderlund & Newman. 2015; Bratman et al. 2012; Depledge et al. 2011) immune system (Arvay. 2018; Williams. 2018; Frumkin et al. 2017) and also it reduces surgery and addiction recovery time. (Soderlund & Newman. 2015; Keniger et al. 2013) Also human physical disorders and diseases would affect by nature connection. For example, remedy symptoms of diabetes type 2, (Soga & Gaston. 2016) cardiovascular, metabolic, gastrointestinal, and respiratory diseases. (Cox & Gaston. 2018; Cox et al. 2016; Keniger et al. 2013; Grinde & pital. 2009) Reducing allergies, headaches, and obesity. (Frumkin et al. 2017; Cox et al. 2016; Grinde & Pital. 2009).

4.2.1.2. *Psychological Health*

According to Leckman and Mayes (1998), there are many indications that alienation from nature in urban life is responsible for the increase in psychological disorders in the modern world. (Salingaros, 2014; Gullone, 2000, p. 311) Modern urban lifestyle's stress and anxiety, are the main causes of psychological disorders and threats to holistic health. On the other hand, being in the nature is one of the most effective factors in reducing stress and anxiety. Theories related to psychological health and nature have been described based on three main categories: cognitive psychology, emotional psychology, and evolutionary psychology. Theories related to psychological health includes attention restoration theory, stress reduction theory, nature preferences theory, Savanah theory, and prospect and refuge. Attention restoration theory expresses the ability to communicate with nature in the renewal and recovery of concentration unconsciously and through the promotion of cognitive function. (Bratman, 2012) This theory justifies improvement of cognitive functioning, problem-solving, learning rate, memory performance, and memory span. Rising creativity, vitality, performance, concentration, and lowering anxiety and sadness. Also human-nature connection impacts on these mental disorders, ADHD, Alzheimer, Parkinson, (Ottosson et al. 2015) dementia, schizophrenia, and derealization. (Williams. 2018) Stress reduction theory states that in the presence of nature, the amount of people's stress decreases unconsciously and spontaneously. (Bratman, 2012) Since stress is the main cause of many disorders and diseases, reducing the amount of stress in people have a great impact on holistic health. According to nature preferences theory, human preferences have grown because they have been important to our survival as human species. The evolutionary view simply states that human beings who have chosen the right environments have survived longer and had more successful births than others, and have transmitted to us the tendency to prefer such environments. Savanah theory refers to the type of region's greenery which is the best for human beings living and survival. Research shows that tropical savannah, especially those with irregular patterns of rocks and caves (for protection), have been the most optimal natural environment for human life and survival. (Hartig et al., 2010, p143) From evolutionary point of view, this is a main reason that people prefer savannah type greenery. The theory of prospect and refuge, in continuation of the previous theories and considering the condition of survival, have introduced environments with prospect and at the same time refuge, suitable spaces for living and survival. (Table1)

4.2.1.3. *Social Health*

Environments that are devoid of any connection with nature, destruct the holistic health of human beings, and cause decline of moral values and behavior of individuals. (Soderlund and Newman, 2017) Social cohesion theory generally represents the social situation, in which individuals work in groups and take into account common goals, have a sense of belonging and trust each other. Research has shown that social cohesion in societies increases with human interaction with nature. (Seymour, 2016) Social health would be improve by, increase in social cohesion, generosity and receptivity, greater desire to help others, better interpersonal relationship, and task performance, and furthermore decrease of violence, crime, aggression, and recidivism.

4.2.1.4. *Spiritual Health*

Previous studies, stated that interaction with nature has a positive effect on people's religious beliefs and improves their spiritual health. (Keniger et al., 2013)

Indicators of spiritual health include giving meaning to life, deep connection to the natural world, increased inspiration, (Beatley, 2017) and spiritual well-being. (Keniger et al., 2013)

Table 1: Theories that impact human health and their correlation with holistic health dimensions

Theories that affect human health by the means of human-nature connection		Holistic health dimensions				
		Physical	Psychology		Social	Spiritual
			Cognitive - Mental	Affective - Emotional		
Physical Activity (Cox et al. 2018; Mazuch R. 2017; Shanahan et al. 2016; Brymer et al. 2010; Grinde & Patil. 2009)		•				
Immune System & Hygiene Hypothesis (Arvay. 2018; Williams. 2018; Beatley T. 2017; Frumkin et al. 2017; Rosenbaum et al. 2017.)		•				
Cognitive Psychology	**Attention Restoration Theory** (Abdelaal MS, Soebarto V. 2019; Lee HC, Park SJ. 2018; Purani K, Kumar DS. 2018; Yin et al. 2018; Rosenbaum et al. 2017; Soderlund & Newman. 2015; McGee B, Marshall-Baker A. 2015; Bratman et al. 2015; Gilis & Gatersleben. 2015; Bratman et al. 2012; Brymer et al. 2010; Grinde & Patil. 2009)	•	•	•		
Affective Psychology	**Stress Reduction Theory** (Abdelaal MS, Soebarto V. 2019; Lee HC, Park SJ. 2018; Purani K, Kumar DS. 2018; Yin et al. 2018; Shanahan et al. 2016; McGee B, Marshall-Baker A. 2015; Bratman et al. 2015; Ottosson J, et al. 2015; Soderlund & Newman. 2015; Gilis & Gatersleben. 2015; Bratman et al. 2012)	•	•	•		
Evolutionary Psychology	**Nature Preferences Theory** (Shanahan et al. 2016; Hartig et al. 2010; Bratman et al. 2012; Gullone E. 2000.)		•	•		
	Savanah Theory (Arvay. 2018; Salingaros. 2015; Hartig et al. 2010; Gullone E. 2000.)	•	•	•		
	Prospect and Refuge (Hartig et al. 2010)		•	•		
Social Cohesion Theory (Cox et al. 2018; Seymour. 2016; Clancy J. 2014; Bratman et al. 2012)					•	

4.3. *Biophilic design elements and patterns*

Dimensions of BD included; 'naturalistic or organic' design and 'place-based or vernacular' design. The organic design dimension, involves forms and shapes in the built environment that directly, indirectly or symbolically elicit the inherent human affinity for nature. The vernacular design reflects in buildings and landscapes that connect to the culture and ecology of a locality or geographical area. (Kellert 2004, Kellert 2005 and Kellert 2008a, 5-6) Six elements of BD are; environmental features, natural shapes, and forms, natural patterns, and processes, light and space, place-based relationships, and evolved human-nature relationships. (Kellert 2008a, 15) All elements together, have 70 attributes, which is the fundamental framework that tells designers what important aspects of nature, should think about when they are designing a building.

5. BIOPHILIC ARCHITECTURE

The BA is a practice of the biophilia theory in a constructed environment. It should satisfy the human needs for relationships with nature in our contemporary living environment.

This study reviewed nearly all of the BD literature including books and papers from 2004 to 2020 (March) by searching for such keywords as "biophilic architecture" and "biophilic building". For this purpose, sentences and phrases that attempted to define a BA or a biophilic building were extracted and analyzed. Apparently, there are nine definitions of BA in the literature. Moreover, there is no common definition upon which all experts agree. Unlike the BD which is often explained by Kellert's definition in many papers and has a clear meaning, BA lacks any explicit definitions.

The notion of BA has been shaped in three components, the first of which analyzes the essence of BA, whereas the second concerns its aim and objectives. Finally, the third component considers the practical scope of BA.

5.1. *Essence of biophilic architecture*

Regarding the main essence of BA, a literature analysis (Table 2) shows that nearly half of the experts (45%) believed in human connection with nature, whereas 33% considered a balanced relationship between human and nature, which would also contain the concept of human-nature connection. Others misled and downgraded the main essence of BA to only some ways of BA practices in architecture through nature-based dialogues and rules governing the natural forms. Therefore, resembling the BD, the main essence of BA is the human-nature connection in a built environment.

Table 2 presents some keywords that can help define the BA in fact, 78% of definitions contain the word "nature", whereas the rest of them use such words as "ecology, habitat, life, culture, and environment", instead.

Table 2- Biophilic Architecture Definitions in Existing Literature

	Year	Name	Main idea	Keyword	Nature		More than Nature
Balanced existence between human and nature	2006	Almusaed A, et al.	formation of balance between human and environment	formation of balance	N[1]		culture, environment
	2007	Joye Y.	overcoming the discrepancy between ancestral and current habitats	-	N		habitat
	2011	Almusaed A.	nature, life and architectural conjecture merge, lively habitable edifice	merge	Y[2]		life, environment
Nature-based inspirations	2014	Ramzy NS.	nature-based dialogue between architectural spaces and a set of human inborn affiliations	nature-based	Y		-
	2015	Ramzy NS.	understanding the rules governing natural forms	-	Y		-
Human and nature connection	2015	Soderlund J. and Newman P.	innate connection with nature should be expressed in their daily lives, better contact with nature within and on buildings	connection, contact	Y		-
	2015	Movahed Kh.	healthy spaces connected with nature	connect	Y		-
	2017	Amanda Sturgeon	reconnect people and nature through buildings, building that will regenerate life	reconnect, regenerate	Y		ecology, culture, history, life
	2019	Abdelaal MS. And Soebarto V.	connecting the built environment to nature	connect	Y		-

5.2. *Biophilic architecture aim*

The goal of BA was analyzed theoretically in the literature, whereas the academic papers sought to determine the implicit impacts of BA on human by reviewing empirical studies. The second part of the BA definition must include the main aims, goals, or objectives of BA Kellert asserted, “We need to extend McDonough’s concept of ecological health to include humans in the ecological equation, recognizing how people’s physical and mental well-being and productivity in the built environment are also contingent on the quality and quantity of their experiential connections with natural systems and processes.” (Kellert 2004, 3) Table 3 demonstrates the main aims and objectives of BA in the current literature.

[1] N=No
[2] Y=Yes

Table 3- Main Aim/Goal and Objectives of Biophilic Architecture from Literature

Year	Name	Health	Well-being	Connect to nature	Other benefits	H &/ E
2006	Almusaed A, et al.	✓	×	✓	moral, social and economic benefits, human performance , environmentally friendly, energy-efficient buildings and developments by effectively managing natural resources	
2007	Joye Y.	×	✓	×	---	N.M.
2011	Almusaed A.	✓	×	×	---	
2014	Ramzy NS.	✓	×	×	productivity	N.M.
2015	Soderlund J. and Newman P.	×	×	×	social, environmental, and economic benefits.	N.M.
2015	Ramzy NS.	✓	✓	×	sense of belonging and neurological nourishment	
2015	Movahed Kh.	×	✓	×	---	
2017	Amanda Sturgeon	×	×	×	Regenerate life	N.M.
2019	Abdelaal MS. And Soebarto V.	✓	✓	×	---	

Accordingly, 78% of experts introduced the retention of health and well-being as the fundamental aims of BA in addition, 55% discussed the other aspects of human-nature connections such as productivity and neurological nourishment as well as social, environmental, and economic advantages. Totally, 55% of experts considered human health, whereas 22% took into account human and environmental health and welfare as the main goals of BA So main goal of BA is human health, and also it is necessary to pay attention to the environmental health and other benefits of nature connection.

5.2.1. *Biophilic architecture empirical implication*

Table 4- Empirical studies in biophilic architecture until (March 2020)

Source	Study Type	Building Function	Aim/Objectives	Method/Measurements	Patterns and Elements
(2020) Hahn N, Essah E, Blanusa T.	Experimental, Case study (40 Participants)	Office workplace	Determination of impacts of presence and absence of nature connection in workplace, on human health, well-being and performance	2 potted plants for each person in their individual office, 8 potted plants in break-out spaces	Potted Plants
(2019) Wallmann-Sperlich B, et al.	Pilot Study (12-24 Participants)	Office workplace	Investigation of active biophilic designed office on sitting time	Online survey on health behavior T_1 One-month pre-relocation, $T_{2\ Three}$-months post-relocation, T_3 Seven-months post-relocation	Open space plan, Potted plants, Natural light, Green wall
(2019) Yin J, et al.	Between-subjects experiment (100 participants)	Office, Indoor environment	Testing restorative effect of biophilic elements on stress and	Combined virtual reality and wearable biomonitoring sensors for testing the restorative effects	Indoor green wall and plants, Windows with view

			anxiety, Recovery time		and daylight, Wooden material, Biomorphic pattern
			Comparison between restorative effects of three different types of biophilic environment	3 type environments: Indoor green, Outdoor View, Combination	
(2019) Yin J, et al.	Randomized crossover (30 participants)	Office, Indoor environment	Exploring effects of biophilic interventions on stress and cognitive function(creativity)	Types of Biophilic interventions and types of office space (Open - enclosed)	Potted plants, Green wall, Biomorphic patterns, Natural materials, Window view, Daylight
			Finding variations in the intensity of virtual exposure to nature	Eye-tracking for exploring intensity of virtual exposure to biophilic elements	
(2018) Yin J, et al.	Randomized crossover (28 participants)	Office, Indoor environment	Examine the physiological and cognitive responses to natural elements	Experienced the biophilic environment for 5-minutes in reality and virtually by using virtual reality	Exposure to natural elements (real and virtual reality)
			Virtual reality vs actual environment		
(2018) Purani K, Kumar D.S.	Empirical (566 usable responses)	Servicescape	Exploration of restorative potential of biophilic servicescapes	4 service context (hospital lobby, upscale restaurants, spa, and bank lobby)	Daylight, Wood material, greenery
(2018) Sanchez J.A, Ikaga T, Sanchez S.V.	Pilot experiment and Case Study (8 participants)	Workplace, Indoor environment	Determination of performance improvement in workplace through BD	2 groups in 5 Cases;(2 no daylight, no greenery and 3 with daylight and greenery)	Greenery, Daylight
(2018) Ortegon-Cortazar L, Royo-Vela M.	Empirical (403 participants)	Shopping Center	Exploring effects of biophilic atmosphere on intention to visit	403 participants distributed in 24 large shopping centers	Biophilic atmosphere
(2017) Rosenbaum M.S, Ramirez G.C, Camino J.R.	Empirical (68 participants)	Lifestyle Center	Investigating restorative potential of biophilic lifestyle center designs	Response to greenery vs no greenery, also with given purposeful shopping or browsing, and given paying full or discount prices	Trees and Plants, Forms of water, Small animal life
(2015) Obiozo R.N, Smallwood J.J.	Focus group study, Case study	Construction Site	Considering green construction site humanistic values	Comparative analysis of two similar construction site	Natural elements
(2015) Ottosson J, et al.	Experimental (5 participants)	Outdoor setting	Investigation of whether passing through hedge openings with or	Parkinson patients walking through hedge openings with or without doorframe	Outdoor natural settings

			without built elements triggered FOG		
(2014) Gray T, Birrell C.	Longitudinal (2 years) Case study (12 participants)	Site office building	Exploring BD impacts on health and performance of site office building occupants	3 months' vs 2 years, Bespoke site design: open plan workspace, natural lighting, ventilation, plants, prospect and view, recycled and non-synthetic materials	natural lighting, ventilation , plants, prospect and view, material
(2013) Rice C.S, Torquati J.C.	Empirical (114 participants)	Natural outdoor setting	Determine whether young children's biophilia was related to the greeness of the play area of the preschool they attend	Testing biophilia score of children with and without natural outdoor play area	Natural outdoor play area

Thirteen papers (Table 4) have directly analyzed the impacts of BA on the dimensions of human health and well-being as well as human behavior in some cases. In fact, 92% of papers have confirmed the positive impacts of BA on the holistic health of humans, and only one paper (83) failed to determine the correlation between BA in outdoor settings and personal biophilia score among children. The common instruments used in these studies were self-report tests, questionnaires, and also certain physical health indicators. Nearly all of these empirical studies were short-time works of research, and there is only one longitudinal (2-year) study (82) studies (62%) were conducted in workplaces, 15% in shopping centers, another 15% in outdoor places, and 8% in Servicescape. The main BA elements analyzed in these studies include potted plants and indoor greenery, natural lighting, natural materials, and biomorphic patterns. In general, these studies show that different elements have diverse impacts, which vary in magnitude in different situations. However, these studies are incomprehensive and limited; therefore, more extensive research must be conducted in other aspects of BD.

5.3. *Biophilic architecture in practice*

Kellert quoted Heerwagen; "BD does not tell a designer or developer what he or she should do, but rather what is important." (Harris, 2012, pviii] In his book titled "Nature by Design: The Practice of Biophilic Design." He established basic principles, practices, and strategies for achieving the BD. This book offers a determined menu of options for designers to apply to their projects, according to their specific circumstances. Also, the most popular BD strategies -fourteen patterns of BD- are not design tools or explaining design techniques. Instead, "these are 14 ways of experiencing nature", designers should adopt that in "response to place." As a result, there is not any definite practical guideline to implement the BD in architecture. The critical point is that the ways of reconnecting with nature through architecture must be consistent with the ecology and culture of the project's place in order to respond appropriately to human needs. There is an urgent need for establishing operational strategies for achieving BA.

5.3.1. *Biophilic architecture implementation*

Table 5- Studies about biophilic architecture implementation until (March 2020)

Source	Building Function	Case Study	Aim/Objective	Solutions	14 Patterns of BD	Kellert's Frameworks
(2020) Parsaee M, et al.	Adaptive Building Facade	-	Improve health and human-nature relations and deal with the extreme climate in Northern Canada	Photobiological and biophilic factors in adaptive facades	✓	✓
					Combination of both	
(2020) Jiang B, et al.	-	-	Incorporating biophilic criteria into green building rating tools (Green Mark and LEED)	Identify the differences and similarities between the Biophilia-related strategies of GM and LEED (BD + C, ND) based on a comprehensive consideration of the potential influencing factors	-	-
(2019) Xue F, et al.	-	-	Shifting for green building rating tools (GBRTs) from energy-oriented towards human-oriented, Incorporating biophilia into green building rating tools	Pair analyzing and finding relations between GBRTs and biophilia	-	-
(2019) Abdelaal M.S.	University Campus	-	Enhance physical, social, intellectual and psychological well-being in creative university campus	Linkage between sustainability, innovation and biophilia	✓	✓
					Combination of both + biophilia values	
(2019) Abdelaal M.S, Soebarto V.	Healthcare (Hospitals)	Royal Children Hospital, Australia	Creating restorative hospitals by human-nature reconnection	Salutogenic and BD principles combination	✓	-
(2019) Cengiz C, Boz A.O.	Children Playground	HortPark Nature Playground, Singapore	Give children with different skills and ability level, opportunities and benefits by biophilic playgrounds	Playgrounds in natural environment with natural elements	✓	-
(2019) Mustafa F.A, Yaseen F.R.	School	Bilkent School, Irbil city, Iraq	Examination the availability of biophilic patterns in Bilkent school Assist in designing future pilot studies in Erbil city	Quantitative approach based on survey questionnaire	✓	-
(2019) Park S.J, Lee H.C.	Childcare Facilities	20 different childcare facilities in Japan	Find the clues to creating an optimized environment for children in nature	Analyzing characteristics of BD patterns in 20 case studies and questionnaire survey from 214 guardians of children	✓	-
(2018) Park S.J, Lee H.C.	Children's Library	20 libraries in different countries	Suggest a space design method for children's library with applying BD patterns	Analyzing characteristics of BD patterns in 20 case studies and questionnaire survey from 261 caregivers of children's libraries	✓	-
(2018) Barreiros C, Veas E, Pammer V.	Industrial design	Coffee machine and workplace device	Improving better device maintenance and user's overall well-being	Using sensory data in devices, by utilizing BD and calm computing	-	-
(2018) Totaforti S.	Hospital	-	Reconnecting individuals with the patterns and processes of nature particularly in healthcare spaces	A new way of thinking in design by considering healing power of nature	✓	-
(2017) Soderlund J, Newman P.	Prison	-	Using nature benefits on humans to providing new way to improve the prison experience	Using nature power in prisons for reduction in recidivism and social benefits	✓	-

(2015) Human Space report	Workplace	-	The global impact of BD in the workplace	Analyzing global reports about BD in workplace	-	-
(2015) Gil P, Rossi C, Coral W.	Urban Building Facade	-	Recovering the lost contact with animals in the urban context	Using artificial intelligence learning technique	-	-

Totally, fourteen studies (Table 5) have been carried out in this field. In particular, 64% of the papers used 14 biophilic design patterns as the basis for BA implementation, whereas 14% employed the Kellert frameworks through the same approach. In these studies, building functions include children's spaces (3 papers), hospitals (2 papers), and façades (2 papers). One paper was also dedicated to each of the other functions, *i.e.* campus, schools, prisons, work environments and industrial designs. Comparisons were then drawn between the results of all papers in different combinations of various approaches and strategies devised to provide principles, guidelines, frameworks, and solutions for BA implementation based on the goals and conditions defined in each paper. However, none of them has yet succeeded in developing a comprehensive and appropriate implementation framework in this regard; hence, more research is required on BA implementation.

6. CONCLUSION

BA is an essential framework for improving a built environment for human life. According to a comprehensive review of literature, BA can be defined as a human-nature reconnection aimed at enhancing human and environmental health and well-being in a built environment through a novel design mindset. The term "reconnection" is used to remind designers to provide people with as much natural atmosphere as possible in order to create a space which closely resembles our ancestors' habitats. Although BA focuses basically on human health and well-being, that human health cannot improve apparently without guaranteeing environmental well-being and ecosystem health. In fact, "Different types and qualities of natural environments affect human health and well-being differently." (Wheeler et al. 2015, Millennium Ecosystem Assessment.) Other advantages of experiencing nature such as social and economic merits are not included in the definition, for they will occur only by developing the human-nature reconnection. The practical aspect of BA is its weakest characteristic, which should be enhanced by causing a paradigm shift in the current design thinking, using a more holistic mindset, and benefiting from an ecological design style. For future research, the practical aspect of BA and evaluation criteria must be investigating thoroughly. Being biophilic is a quality of space which would affect inhabitants. The quantification and measurement of biophilic spatial qualities require special analysis for finding beneficial techniques. Moreover, another interdisciplinary objective is to determine the correlation between these spatial qualities as well as the type and extent of impacts on human health and environmental well-being. Furthermore, the most intriguing and important topics of high research potential include establishing the criteria for determining how to obtain the optimal correlation between human and natural environment well-being and developing effective BA. The current BA interpretation fails to meet the evolutionary needs of humans through a human-nature connection in a built environment, something which should be given special emphasis in future studies, to help designers and architects for achieving real impressive BA.

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