

The Effects of Biophilic Design on People's Psychological Outcomes: A Review of Literature

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ABSTRACT

This study investigates the evidence supporting the impacts of biophilic design on the psychological outcomes for participants within various settings. Designing by biophilic design principles and implementing biophilic elements in everyday spaces may potentially impact the psychological well-being of individuals. Prior research has suggested that the biophilic design can contribute to positive mental health outcomes. Reporting the most recent evidence may assist designers in making informed decisions. In this study, a literature review was conducted within six main scientific databases. A total number of 13 articles were included. Each psychological outcome affected by biophilic design principles were discussed in detail. The main psychological outcomes affected by biophilic elements are 1) stress, 2) anxiety, 3) mood, 4) perception, 5) fatigue, 6) restorative effects, 7) cognition, 8) social well-being, 9) nature relatedness and 10) behavior. Although several studies have provided a high level of evidence, other studies have lacked a robust research design.

INTRODUCTION

The term biophilia was used for the first time by Erich Fromm in 1960, describing the human tendency to be fascinated by living things and suggests that exposure to environments that are high on natural features (greenery, natural light and water), is associated with better mental health outcomes in people^[1, 2]. The hypothesis of biophilia was then proposed by Edward O. Wilson, defined as an innate 'bio-centric' affinity with the natural environment as well as an emotional affiliation toward nature that is rooted in the long-evolved relationship between nature and human being and humanity's origin in nature^[3-6]. Biophilia also explains people's positive response to indoor nature and is the idea behind the biophilic design philosophy^[3, 7]. Biophilic design encourages the use of natural processes as well as natural elements to connect people inside buildings with the nature outside of them through relevant design patterns in the built environment^[8, 4]. It also recognizes the innate human affiliation with nature and the need to interact with natural environment^[9]. A growing body of research suggests that human beings have a biophilic need that is related to its evolution in nature and the fact that humans are genetically programmed to function effectively in natural environments^[10, 11]. A large number of empirical evidence in different settings such as workplaces classrooms community spaces healthcare centers and residential areas verify the positive impacts of biophilic design on human well-being and behavior^[7, 12-23]. For instance, natural lighting, greenery and window views are proved to not only be beneficial for increasing productivity, collaboration and a sense of satisfaction among employees and boost their cognitive performance, but also to decrease their level of stress and anxiety^[12, 13, 14, 24]. The healing capability of contact with nature is also proved to be beneficial for life satisfaction, psychological well-being, social inclusion, social cohesion, a sense of community and positive perception in different kinds of settings^[7, 12, 15, 19, 21, 25]. Aside from biophilia hypothesis, attention restoration theory can be used to explain how exposure to nature can improve the psychological state and behavior^[26]. Attention Restoration Theory (ART) suggests that negative emotions could be decreased through the restorative effects of natural environments such as parks, beaches and forests, and spending time in such settings enables people to recover from stress and mental fatigue and its symptoms^[27, 28]. These settings typically contain the four environmental properties: being away, extent, fascination and compatibility^[27, 29]. Experimental studies suggest that the environments containing birds' sounds, greenery, water and sky view are extremely beneficial for heightening restorative perception psychological restoration and cognitive restoration^[16, 19, 20, 22]. This article reviews empirical evidence for the effects of

biophilic elements in different places on people’s psychological state and behavior on the basis of two theoretical frameworks: attention restoration theory and biophilia hypothesis [3, 26]. This review seeks to answer the question, “what are the effects of biophilic design on the people’s behavior and psychological state in certain places such as school, community spaces, workspaces and therapeutic gardens.

EXPERIMENTAL DETAILS

Methods

The search was limited to scholarly publications written in English and published between 2010 and 2020. Six databases (Elsevier, Nature, ProQuest, Sage, Scopus, Springer) were searched. The search model demonstrated in **Figure 1** was used to form the search formula, and the keywords searched were in two main categories including biophilia related (biophilia, biophilic design) and psychological behavior related (behavior, psychological well-being) as shown in **Figure 2**. The search strategy followed the Preferred Reporting Items for Systematic Reviews And Meta-Analysis (PRISMA) model (**Figure 1**). All articles included in this study met the following criteria:

- they were empirical studies written in English and published between 2010 and 2020,
- they investigated the effects of biophilic elements on participants’ psychological state,
- they were all experimental and quasi-experimental studies.

In this review, “psychological outcomes” refer to participants’ psychological states, stress, anxiety, mood, perception, fatigue, restorative effects, cognition, social well-being, nature relatedness, and behavior. The relevance of each article was evaluated in three steps:

- a review of its title,
- a review of its abstract, and
- a review of its full text.

Each article judged to be relevant and included in the final list was evaluated again and assessed for eligibility and in the final stage, only the experimental and quasi experimental studies were chosen as the final articles. The search, analysis, and synthesis were conducted from June 2020 to February 2021 by a team of environmental design researchers.

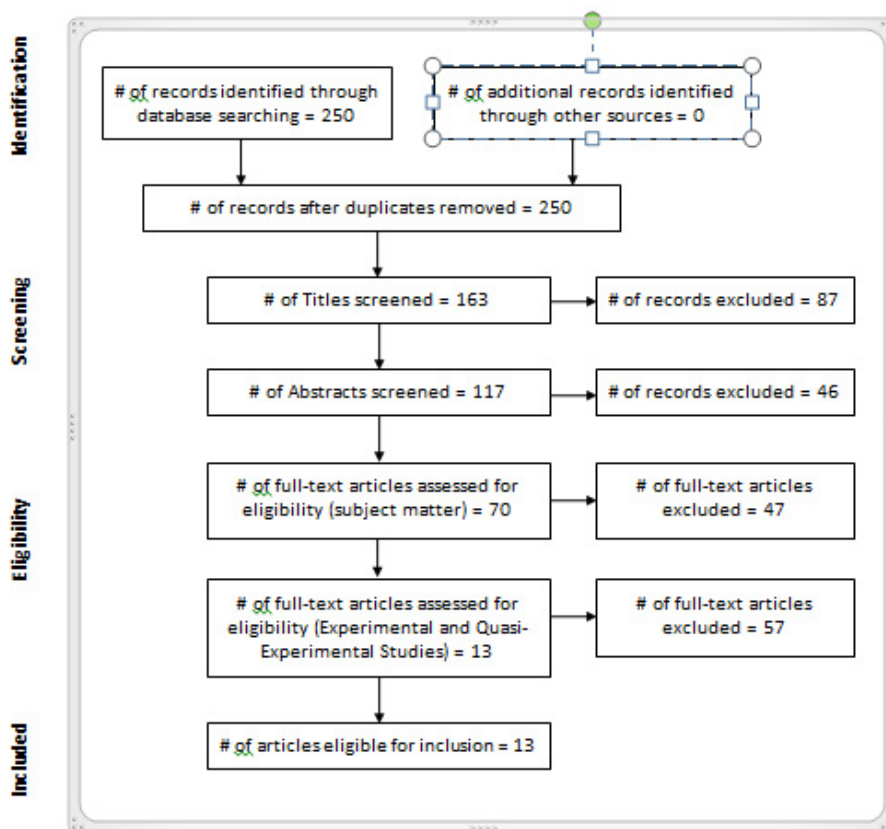


Figure 1. Methodology of the Literature Review Search Process based on Moher [30].

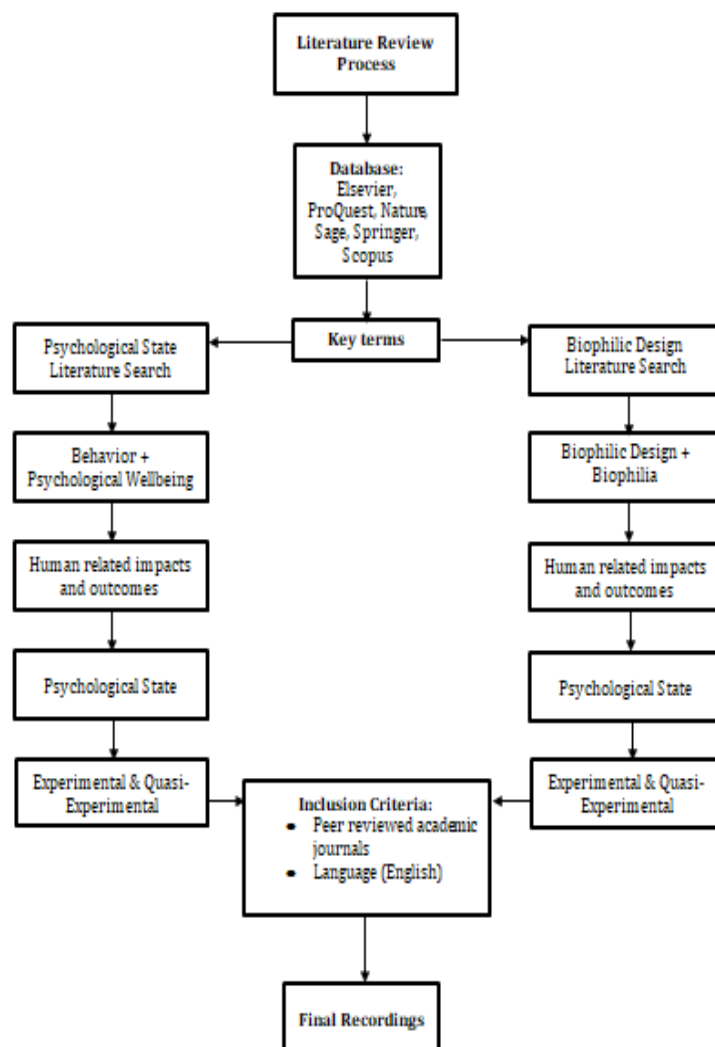


Figure 2. Narrative methodology.

RESULTS AND DISCUSSION

A total of 13 articles satisfied the inclusion criteria. **Figure 1** is a graphical representation of the search process. As a result of the search, ten classes of participants’ psychological outcomes were identified: stress, anxiety, mood, perception, fatigue, restorative effects, cognition, social well-being, nature relatedness, and behavior. **Table 1** lists the included articles by the class of psychological outcomes. The following narrative synthesizes the key components and findings of each study and includes a table for each class of participant outcome. It is divided among subheadings for the classes of participant outcomes and the aspects of biophilic elements that affect those outcomes.

Table 1. Categorized list of articles based on psychological outcome.

Psychological outcome	Intervention	Setting	Citation
Stress	Natural lighting, Greenery, Ventilation, Non-synthetic material, Window view, Indoor green (VR), Outdoor view (VR), Bird's sound	Workplace	(Ayuso Sanchez et al., 2018; Gray and Birrell, 2014; Kelz et al., 2015; Purani and Kumar, 2018; Yin et al., 2020a) ^[12, 13, 19, 24]
Anxiety	Indoor green (VR), Outdoor view (VR), Greenery, Natural art activities	Workplace, Therapeutic garden	(Sia et al., 2020; Yin et al., 2020a) ^[21]

Mood	Environmental education, Greenery, Water, Natural lighting, Ventilation, Non-synthetic material, Window view	Classroom, Hotel, Workplace, Schoolyard	(Ayuso Sanchez et al., 2018; Benfield et al., 2015; Gray and Birrell, 2014; Kelz et al., 2015; Lee, 2019a; Mangone et al., 2017; Nisbet et al., 2011; Purani and Kumar, 2018; van den Bogerd et al., 2020) ^[12-17, 19]
Perception	Window view, Greenery, Natural lighting, Nature art activities, Non-synthetic material	Classroom, Workplace, Therapeutic garden, Utility and hedonic services	(Ayuso Sanchez et al., 2018; Benfield et al., 2015; Lee, 2019a; Purani and Kumar, 2018; Sia et al., 2020; van den Bogerd et al., 2020) ^[7, 12, 15, 18, 19, 21]
Fatigue	Greenery, Water, Bird's sound, Natural lighting, Non-synthetic material	Lifestyle Center, Classroom, Workplace, Utility and hedonic services	(Purani and Kumar, 2018; Rosenbaum et al., 2018; van den Bogerd et al., 2020) ^[7, 19, 20]
Psychological restoration	Window view, Greenery, Natural lighting, Non-synthetic material, Environmental education, Water	Residential area, Utility and hedonic services, Classroom, Schoolyard	(Kelz et al., 2015; Mangone et al., 2017; Masoudinejad and Hartig, 2020; Nisbet et al., 2011; Purani and Kumar, 2018; Rosenbaum et al., 2018) ^[14, 16, 17, 19, 20, 22]
Cognitive performance	Greenery, Natural lighting, Ventilation, Non-synthetic material, Window view, Water	Workplace, Classroom, Schoolyard	(Ayuso Sanchez et al., 2018; Benfield et al., 2015; Gray and Birrell, 2014; Kelz et al., 2015; Mangone et al., 2017; Purani and Kumar, 2018; Sia et al., 2020; van den Bogerd et al., 2020) ^[7, 12-16, 19, 21]
Social well-being	Water, Greenery, Bird's sound, Window view, Natural lighting, Non-synthetic material, Ventilation	Lifestyle Center, Workplace	(Gray and Birrell, 2014; Rosenbaum et al., 2018) ^[13, 20]
Behaviour	Water, Greenery, Bird's sound, Natural lighting, Window view	Lifestyle Center, Hotel, Classroom	(Benfield et al., 2015; Lee, 2019a; Rosenbaum et al., 2018; van den Bogerd et al., 2020) ^[7, 15, 20]
Nature relatedness and ecological understanding	Environmental education	Classroom	(Nisbet et al., 2011) ^[17]

Stress

Five studies investigated the effects of biophilic design on stress levels (**Table 2**)^[12, 13, 16, 24]. Three of the studies were experimented in workplace settings and the other two studies were in classroom and schoolyard environments. One study measured the physiological state of office workers to determine the effects of natural elements on their stress reduction^[13]. By using photographs and video footage of natural lighting, greenery, ventilation, a window view and bird's sound the authors concluded that the stress level of workers had decreased significantly. In another experimental study the impact of flowers and potted plants on employee performance was investigated^[14]. By measuring the heart rate and eardrum temperature, and also analyzing participant's saliva in the simulated environment, decreased levels of stress were confirmed. One other study experimented the effects of indoor greenery, natural lighting and the combination of the two in four virtual indoor offices on participants^[24]. The results of this study showed that the participants heart rate variability, skin conductance level, and blood pressure were in consistent with lower levels of stress at the end of the experiment. Another study has also found evidence that exposure to biophilic elements in a schoolyard setting can positively influence physiological stress states of pupils^[16]. Although, one of the experimental studies investigating the impact of indoor potted plants and green walls on student's well-being, found that the change in blood pressure measurements were statistically insignificant^[7].

Table 2. Stress and biophilic design.

Setting	Participants	Study Design	Intervention	Outcome	Citation
Work place	Office workers	Experimental	Recycled planter box, Vegetable garden, Window view, Ventilation, Natural lighting, Bird's sound	Stress=Decreased	(Gray and Birrell, 2014) ^[13]
	N=12				
	(males, N= 10; females, N = 2)				
	Age: 25- 47				
Work place	(male= 27-41; female= 25)	Experimental	Flower, Potted plants	Stress=Decreased (Evaluation: Saliva analysis, heart rate, eardrum temperature, blood pressure)	(Ayuso Sanchez et al., 2018) ^[12]
	College students				
	N=8				
Work place	(male, N=8)	Experimental	Indoor green (VR), Window view (VR), Combination	Stress=Decreased (Evaluation: heart rate variability, skin conductance level, blood pressure)	(Yin et al., 2020b) ^[24]
	Faculty staff and students N=100				
	(male, N=37; female, n=63) Age: 29±12				

Classroom	Study 1: first-year Bachelor Biomedical Science students	Experimental	Interior plants (Codiaeum species, Dracaena species, Sansevieria, Dieffenbachia), Green walls, Potted plants	Stress=NS*	(van den Bogerd et al., 2020) ^[7]
	N=70			(Evaluation= Environmental assessment scale)	
	(male, N=8; female, N=62), Age: 18-24, Mean=19.5, Study2: Secondary school students				
	N=213				
	(male, N=101; female, N= 112)				
	Age: 12-18, Mean= 14/53				
	Study3: secondary vocational school students				
Schoolyard	School pupils	Quasi-Experimental	Shrubs, Potted plants, Drinking fountain	Stress=Decreased (Evaluation: blood pressure)	(Kelz et al., 2015) ^[16]
	N=133				
	(male, N=68; female, n=65) Age: Exp. G.=14; C.G.=14)				

Anxiety

Two of the studies investigated the effects of biophilic elements on participant’s anxiety levels (**Table 3**)^[21,24]. One of the studies that had used virtual reality based offices based on biophilic design principles, also analyzed the anxiety levels of contributors by measuring the same indicators (participants heart rate variability, skin conductance level, and blood pressure) for stress levels and found that the anxiety levels in the simulated environment had also been decreased^[24]. The other study examined the effects of nature-based activities in public and therapeutic gardens on elderly participants from three senior day care centers. In this experimental study Sia engaged participants in horticulturally based activities and by analyzing the Zung self-rating depression scale found that the anxiety levels of participants had decreased significantly over time^[21].

Table 3. Anxiety and biophilic design.

Setting	Participants	Study Design	Intervention	Outcome	Citation
Therapeutic Garden	Elderly participants from three senior day care centers	Experimental	Horticulturally based activities, Growing pea sprouts and vegetables, Setting up planters	Anxiety= Decreased (Evaluation=Zung self-rating depression scale)	(Sia et al., 2020) ^[21]
	N=47 (male, N=14; female, N=33) Age: 60-95, Mean=77.5				
Workplace	Faculty staff and students N=100	Quasi-Experimental	Indoor green (VR), Window view (VR), Combination	Anxiety= Decreased (Evaluation: heart rate variability, skin conductance level, blood pressure)	(Yin et al., 2020b) ^[24]
	(male, N=37; female, n=63) Age: 29 ± 12				

Mood

Nine of thirteen empirical studies investigated the effects of biophilic design on participants’ mood including their morale, work satisfaction, overall mood, motivation, emotional well-being and vitality (**Table 4**)^[7, 12-19].

Morale

Gray and Birrell found that exposure to biophilic elements such as natural lighting, greenery and a window view in work spaces can have a positive effect on workers’ mood swings and specifically on morale states of participants^[13].

Work Satisfaction

Two of the experimental studies inspected work satisfaction of participants in office, utilitarian and hedonic service envi-

ronments [13, 19]. The first study which had exposed office workers to biophilic elements such as natural lighting, greenery and a window view in the office found that not only had this experiment impacted morale states of participants, but the observations indicated that work satisfaction had also increased upon the office workers [13]. Purani and Kumar also examined work satisfaction in two different settings; hospital and bank environments (utilitarian services), and up-scale restaurant and spa (hedonic services) [19]. The results indicated that biophilic elements in these spaces had increased work satisfaction among participants.

Overall Mood

Participants. In another study the results based on a questionnaire specified that the overall mood of participants increased when they experienced natural elements such as non-synthetic materials, greenery and natural lighting [19]. One other recent study investigated the effects of interior plants, potted plants and green walls in classroom environments on student outcomes, and one the positive outcomes was the rising of participants’ overall mood states [7].

Motivation

Ayuso Sanchez experimented the effects of natural lighting in workplace settings on student’s motivation towards work [11]. The saliva analysis, heart rate, eardrum temperature, and blood pressure were measured during the experimental and the results showed substantial improvement in motivational states of participants.

Emotional Well-being

Three studies in three different setting studied the outcomes of emotional well-being [14, 17, 18]. The first experimental study examined the outcomes of emotional well-being and favorable attitude on undergraduate students in an upper scale hotel by a questionnaire involving greenery, water and natural lighting [18]. By evaluating the results through the 7-point semantic differential scale and ANOVA the author found that both outcomes had a positive correlation. Emotional well-being of knowledge workers in the workplace was examined in the second study by integrating natural environments with the building and surprisingly, the results showed significant increase in the overall well-being state of participants [14]. Nisbet examined the effect of nature-relatedness on subjective well-being and one of the outcomes was specifically emotional well-being [17]. The New Ecological Paradigm Scale, the New Ecological Consciousness Scale, and the 3 Ecology sub-scales were used to evaluate the outcomes and it was concluded that the state of emotional well-being increased significantly [31].

Vitality

Nisbet explored nature relatedness as a contributor to subjective well-being including emotional experience and vitality through three different study plans [17]. The results did not show any certain pattern of increase or decrease throughout the experiment and the results were statistically insignificant and unstable.

Table 4. Mood and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Morale, work satisfaction	Workplace	Office workers	Experimental	Recycled planter box, Vegetable garden, Window view, Ventilation, Natural lighting, Bird's sound	Morale=increased	(Gray and Birrell, 2014) [13]
		N= 12			Work satisfaction = increased	
		(males, N=10; females, N=2)				
		Age: 25- 47				
		(male= 27-41; female= 25)				
Overall mood	Classroom	Undergraduate students	Quasi-Experimental	Window view	Overall mood=increased	(Benfield et al., 2015)[15]
		N=567				
		(male, N=284; female, N=283)				
Motivation	Workplace	College students	Experimental	Natural lighting	Motivation= increased (Evaluation: saliva analysis, heart rate, eardrum temperature, blood pressure)	(Ayuso Sanchez et al., 2018)[12]
		N=8				
		(male, N=8)				
Overall mood, work satisfaction	Utilitarian and Hedonic services	Undergraduate business students	Experimental	Greenery, natural	Overall mood= increased, Work satisfaction=increased (Method= MANCOVA)	(Purani, 2018) [19]
		C.G.: N=60; Exp. G.: N=283 (male, N=237; female, n=46) Age, Exp. G. =18-44; C.G. =X>18)		(wooden) finishes (for walls and floors), natural lighting		

Emotional well-being, favorable attitude	Hotel (upper midscale)	Pilot study: Undergraduate students	Experimental	Plants, water, natural lighting	Emotional well-being=Increased	(Lee, 2019b) ^[18]
		N=36			Favorable attitude=increased	
		(male, N=9; female, N=27) Age: 20-57, Mean=24/97 Main study: N>9=have a college degree or higher			(Evaluation: 7-point semantic differential scale and ANOVA)	
		N=246				
		(male, N=152; female, N=94) Age: 44%=26-34, 22%=18-25, 19%=35-44				
Overall mood	Classroom	Study1: first-year Bachelor Biomedical Science students	Experimental	Interior plants (Codiaeum species, Dracaena species, Sansevieria, Dieffenbachia), green walls, potted plants	Overall mood=increased	(van den Bogerd et al., 2020) ^[7]
		N=70				
		(male, N=8; female, N=62) Age: 18-24, Mean=19.5 Study2: Secondary school students				
		N=213				
		(male, N=101; female, N=112)				
		Age: 12-18, Mean=14/53 Study3: secondary vocational school students				
N=161						
Emotional well-being	Workplace	Knowledge workers	Experimental	Integrating natural environments with the building	Emotional well-being=increased	(Mangone et al., 2017) ^[14]
		N=64				
		(male, N=40; female=24)				
		Age, Mean=41/6				
Vitality, emotional well-being, emotional experience, vitality	Classroom	Study 1: Canadian undergraduate students N=184	Quasi-Experimental	Nature relatedness, Environmental education	Vitality=Uncertain	(Nisbet et al., 2011) ^[17]
		(male, N=60; female, N=124)			Emotional well-being=increased	
		Age, mean=19.48			(Evaluation= the new Ecological Paradigm Scale, the New Ecological Consciousness Scale, and the 3 Ecology sub-scales)	
		Study 2: Federal government and private sector				
		N=145				
		(male, N=58; female, N=87) Age: 37-42				
		Study 3: Undergraduate students at a Canadian university				
Age, Mean=19/35						
Exp. G.= Experimental Group, C.G.= Control Group						

Perception

In six experimental and quasi-experimental studies people’s perception by biophilic elements was investigated in different settings (Table 5) [7, 12, 15, 18, 19, 21].

Positive Perception and Classroom Experience

One study examined the impact of a window view on participants’ perception and overall experience of space; in this case the classroom [15]. By evaluating the experiment through a 5-point Likert-type scale the authors found that perception of course materials, quality of course curriculum, and overall experience of the classroom was positively impacted among undergraduate students.

Workload Perception

In one of the studies based in the workplace the workload perception of college students after exposure to natural lighting and greenery was evaluated through the measurement of saliva, heart rate, eardrum temperature, and blood pressure [11]. The results indicated a general decrease in the negative perception of workload among participants.

Customer Perception

Another study based in two utilitarian and hedonic service settings suggested that implementing greenery, natural (wooden) finishes for walls and floors, and natural lighting in banks and hospital areas and also up-scale restaurants and spas increased the customer perception, according to the MANCOVA method used in the study [19].

Momentary Effect

In a study by Sia the momentary effect of elderly participants of three senior day care centers participating in horticulturally based activities was evaluated by using the Visual Analogue Scale (VAS) [21]. The results of this study indicated that being involved in nature-based activities increased the momentary effect of participants.

Classroom Attractiveness

van den Bogerd examined the effects of different plant types and green walls in the class on classroom attractiveness as seen by attending students [7]. The Environmental Assessment Scale was used to evaluate the outcomes and the final results indicated that the classroom attractiveness had significantly increased.

Table 5. Perception and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Positive perception, Classroom experience	Classroom	Undergraduate students	Quasi-Experimental	Window view	perception of course materials, quality of course curriculum, classroom resources= Increased	(Benfield et al., 2015) ^[15]
		N=567			Classroom experienced= Increased	
		(male, N=284; female, N=283)			(Evaluation= 5-point Likert-type scale)	
Workload perception	Workplace	College students	Experimental	Natural lighting+ Greenery (plants selected according to the classification made by the NASA study of plants)	Workload perception=Decreased (Evaluation: saliva analysis, heart rate, eardrum temperature, blood pressure)	(Ayuso Sanchez et al., 2018) ^[12]
		N=8				
		(male, N=8)				
Customer perception	Utilitarian and hedonic services	Undergraduate business students	Experimental	Greenery, Natural	Customer perception of quality= Increased (Method= MANCOVA)	(Purani, 2018) ^[19]
		C.G.: N=60; Exp. G.: N=283		(wooden) finishes (for walls and floors), Natural lighting		
		(male, N=237; female, n=46) Age: Exp. G. =18-44; C.G. =X>18)				

Customer perception	Hotel (upper midscale)	Pilot study: Undergraduate students N= 36 (male, N= 9; female, N= 27) Age: 20-57, Mean= 24/97 Main study: N>91= have a college degree or higher N=246 (male, N= 152; female, N=94) Age: 44%=26-34, 22%=18-25, 19%=35-44	Experimental	Plants, Water, Natural lighting	Customer perception of quality= Increased (Evaluation: 7-point semantic differential scale)	(Lee, 2019b) ^[18]
Momentary effect	Therapeutic Garden	Elderly participants from three senior day care centers N=47 (male, N=14; female, N=33) Age: 60-95, Mean = 77.5	Experimental	Horticulturally based activities, Growing pea sprouts and vegetables, Setting up planters	Momentary effect= Increased (Evaluation= Visual analogue scale (VAS))	(Sia et al., 2020) ^[21]
Classroom attractiveness	Classroom	Study1: first-year Bachelor Biomedical Science students N=70 (male, N=8; female, N=62) Age: 18-24, Mean=19.5, Study2: Secondary school students N=213 (male, N=101; female, N=112) Age: 12-18, Mean= 14/53, Study3: secondary vocational school students N=161 (male, N=60; female, N=101) Age: 15-27, Mean=17/8	Experimental	Interior plants (Codiaeum species, Dracaena species, Sansevieria, Dieffenbachia), Green walls, Potted plants	Classroom attractiveness= Increased (Evaluation= Environmental assessment scale)	(van den Bogerd et al., 2020) ^[7]
Exp. G.= Experimental Group, C.G.= Control Group						

Fatigue

In four experimental studies the effects of biophilic design on individuals’ mental and attentional fatigue were investigated (Table 6)^[7, 11, 19, 20].

Mental Fatigue

Participants’ fatigue in the selected experiments can be divided into two main categories; mental fatigue and attentional fatigue. Three studies investigated the mental fatigue of participants impacted by biophilic design using questionnaires and a simulated environment^[12, 20]. The first study examined the effects of bird’s sound, natural elements, water, and greenery in a lifestyle center and concluded that the mental fatigue of participants decreased^[20]. The second experiment examined saliva, heart rate, eardrum temperature, and blood pressure after exposure to natural lighting and found that the mental fatigue of students decreased^[11]. The third study examined the same outcome in a servicescape by using the MANCOVA method and found that the mental fatigue of participants decreased significantly^[19].

Attentional Fatigue

One of the experimental studies in the classroom setting analyzed the attentional fatigue outcomes of participants by using a questionnaire and simulated environment and the results indicated a slight decrease in the attentional fatigue of participants^[7].

Table 6. Fatigue and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Mental fatigue	Lifestyle center	Study1: private university students	Experimental	Bird's sound, Natural elements, Water, Greenery	Mental fatigue=Decreased, (Method= MANOVA, ANOVA)	(Rosenbaum et al., 2018) ^[20]
		N=68				
		(male, N=38; female, N=30)				
		Age: 17-41, Mean=23/91				
		Study2: large private university students				
		N=120				
(male, N=65; female, N= 55)	Experimental	Bird's sound, Natural elements, Water, Greenery	Mental fatigue=Decreased, (Method= MANOVA, ANOVA)	(Rosenbaum et al., 2018) ^[20]		
Age: 18-26, Mean= 18/76						
Study3: large private university students						
N=120						
(male, N=53; female, N=67)						
Age: 19-53, Mean=23/39						
Mental fatigue	Workplace	College students	Experimental	Natural lighting	Mental fatigue= Decreased	(Ayuso Sanchez et al., 2018) ^[12]
		N=8			(Evaluation: saliva analysis, heart rate, eardrum temperature, blood pressure)	
		(male, N=8)				
Mental fatigue	Servicescape	Undergraduate business students	Experimental	Greenery, Natural	Mental fatigue= Decreased	(Purani, 2018) ^[19]
		C.G.: N=60; Exp. G.: N=283 (male, N=237; female, n=46) Age, Exp. G. =18-44;		(wooden) finishes (for walls and floors), Natural lighting	Customer perception of quality= Increased (Method= MANCOVA)	
		C.G. =X>18)				
Attentional fatigue	Classroom	Study1: first-year Bachelor Biomedical Science students	Experimental	Interior plants (Codiaeum species, Dracaena species, Sansevieria, Dieffenbachia), green walls, potted plants	Attentional fatigue= Decreased	(van den Bogerd et al., 2020) ^[7]
		N=70				
		(male, N=8; female, N=62) Age: 18-24, Mean=19.5				
		Study2: Secondary school students				
		N=213				
		(male, N=101; female, N= 112)				
Age: 12-18, Mean= 14/53,	Experimental	Interior plants (Codiaeum species, Dracaena species, Sansevieria, Dieffenbachia), green walls, potted plants	Attentional fatigue= Decreased	(van den Bogerd et al., 2020) ^[7]		
Study3: secondary vocational school students						
N=161						
(male, N=60; female, N=101)						
Age: 15-27, Mean=17/8						

Exp. G.= Experimental Group, C.G.= Control Group

Restorative Effects

Six empirical studies investigated the effects of biophilic elements such as window view, greenery, natural lighting, non-synthetic material, water on the level of restoration among participants, based on the attention restoration theory (Table 7) ^[14, 16, 17, 19, 20, 22].

Restorative Perception

An experimental study investigated the association between restorative perception and biophilic design in a lifestyle center. Rosenbaum exposed participants to a video that depicted a green and non-green version of a same lifestyle center [20]. They found that consumers who were exposed to the lifestyle center with natural elements (greenery and fountains) reported higher perceptions of environmental properties (being away, extent, fascination, compatibility) that embody a restorative setting than those exposed to the non-green version of the same lifestyle center. Kelz in a quasi-experimental study suggested that the level of restoration perceived in a renovated green school yard were higher than that of perceived in a school yards before renovation by measuring four scales (being away, fascination, coherence, compatibility) [16].

Psychological Restoration

Masoudinejad and Hartig examined the effects of window view and the amount of sky on psychological restoration within the residential context. Their strategy was that different images would be rated on all of the psychological variables (being away, fascination, restoration likelihood, preference). The founding of this experimental study revealed that restoration likelihood judgments were directly influenced by the amount of sky and window box with greenery [22]. The view with the most amount of sky perceived most restorative via increased a sense of being away and fascination, and window box produced greater restoration through a sense of being away.

Psychological Well-being

A pre-post quasi-experimental study investigated the effects of greening a school yard on psychological well-being among pupils [16]. The results suggested that their level of psychological well-being were significantly increased after the renovation of the school yard. As hypothesized, students in the school after renovation reported more psychological well-being than those were in the two control (pre-renovation) schools. In another quasi-experimental study Nisbet suggested that environmental education increased connectedness with nature that in turn contributed to psychological well-being. After measuring the six subscales of the psychological well-being inventory (autonomy, environmental mastery, personal growth, purpose in life, positive relationship with others, self- acceptance, satisfaction with life), Nisbet found that there was remarkable correlation between nature relatedness and psychological well-being [17].

Cognitive Restoration

Purani and Kumar in an experimental study suggested that participants exposed to a biophilic servicescape reported higher cognitive restorative (high on being away and fascination) compared to those exposed to a non-biophilic servicescape [19].

Table 7. Restoration and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Restorative perception	lifestyle center	Study1: private university students	Experimental	Bird's sound, Natural elements, Water, Greenery	Restorative perception=Increased (Evaluation= 7 point Likert-type scale: being away, extent, fascination, compatibility, MANOVA, ANOVA)	(Rosenbaum et al., 2018) ^[20]
		N=68				
		(male, N=38; female, N=30)				
		Age: 17-41, Mean=23/91				
		Study2: large private university students				
		N=120				
		(male, N=65; female, N=55)				
Age: 18-26						
Mean= 18/76						
Study3: large private university students, N=120						
(male, N=53; female, N=67)						
Age: 19-53, Mean=23/39						
Psychological restoration	Residential area	Undergraduate students	Experimental	Window view, Flower box, Sky view	Psychological restoration=Increased (Evaluation= MEDIATE macro for SPSS published by Hayes)	(Masoudinejad and Hartig, 2020) ^[22]
		N=212				
		(male, N=43; female, N=168)				
Age: 18-24						

Cognitive restoration	utilitarian and hedonic services	Undergraduate business students C.G.: N=60; Exp. G.: N=283	Experimental	Greenery, Natural	Cognitive restoration= Increased	(Purani and Kumar, 2018) ^[19]
		(male, N=237; female, n=46)		(wooden) finishes (for walls and floors), Natural lighting	(Method= MANCOVA)	
		Age, Exp. G. =18-44; C.G. =X>18)				
Psychological well-being, Restorative perception	Schoolyard	School pupils, N=133 (male, N=68; female, n=65)	Quasi-experimental	Shrubs, Potted plants, Drinking fountain	Psychological well-being= Increased, Restorative perception=Increased (Evaluation= the perceived restorativeness scale)	(Kelz et al., 2015) ^[16]
		Age, Exp. G. =14; C.G. =14)				
Psychological well-being	Classroom	Study1: Canadian undergraduate students	Quasi-Experimental	Environmental education	Psychological well-being= Increased, (Evaluation= The 54-item version of the Psychological Well-being Inventory, 5-point Likert scale)	(Nisbet et al., 2011) ^[17]
		N=184				
		(male, N=60; female, N=124)				
		Age: Mean=19.48				
		Study2: Federal government and private sector				
		N=145				
(male, N=58; female, N= 87)						
Age: 37-42,						
Study3: Undergraduate students at a Canadian university, Age: Mean=19/35						
Exp. G.= Experimental Group, C.G.= Control Group						

Cognition

In eight of thirteen studies the effects of biophilic design on people’s cognition were inspected ^[7, 16]. In this study cognition includes productivity, course grade, creativity, cognitive performance, attention and executive functioning (Table 8) ^[12-15, 19, 21].

Productivity

Gray and Birrell in an experimental study investigated the effect of incorporating aspects of biophilic design in a workplace on the level of productivity ^[13]. According to the authors reported levels of productivity in the transformed biophilic site office was higher than that of reported in the previous non-biophilic site office ^[13]. In another experimental study Purani and Kumar suggested that the productivity of employees working in the servicescape was influenced by the biophilic elements such as greenery and natural lighting ^[19]. The results revealed that service employees would likely to be more productive in a biophilic servicescape when serving customers in comparison with the non-biophilic servicescape.

Course Grade

In a quasi-experimental study, the impacts of the presence of natural views on the grades of a college writing course students were investigated in two identically designed classrooms ^[15]. One group of undergraduate students were exposed to a natural view, while another group were exposed to a concrete retaining wall. While no significant difference in grades was observed in the midterm grades, the final grades reported by the course instructor in the natural window-view classroom was higher than the ones reported in the classroom with concrete-view condition.

Creativity

An experimental study investigated the effect of natural outdoor environment on creativity in a workplace ^[14]. They exposed knowledge workers to images of natural outdoor and constructed indoor offices. According to the authors natural outdoors workspaces were found to be among the most popular choices for creative activities like brainstorming, and the enclosed workspaces were also chosen for the creative tasks but less frequently ^[14]. Ayuso Sanchez suggested that biophilic designed workplaces is significantly associated with the creativity ^[11]. In this experimental study subjects were exposed to the simulated environment. The findings revealed that in a biophilic workplace where daylight and greenery were combined as variables, participants had 4.92 points more in creative task scores. According to the authors, daylight contributed to the performance of creative tasks ^[11].

Cognitive Performance

Mangone compared constructed indoor workspace to outdoor natural workspace ^[14]. They suggested that interaction with

natural environment is associated with higher cognitive performance. The results revealed that nearby nature or natural environment integrated with the building is ideal for cognitively demanding activities that knowledge workers are engaged in. Ayuso Sanchez also examined the correlation between intellectual performance and natural elements^[141]. The participants were placed in the simulated environment for four days. They found that the level of cognitive function reported in a place where greenery and daylight existed were higher than the control group. Another experimental study in which multiple biophilic variables were investigated, Purani and Kumar investigated the effects of biophilic elements on cognitive performance in utilitarian and hedonic services^[149]. Participants were exposed to two sets of photographs, one set that biophilic elements were present, and the other set biophilic elements did not exist. They suggested that perceived biophilic servicescape had more cognitive restorative effect compared to non-biophilic servicescape. Sia examined the long-term effects of urban greenery on the cognitive performance of older adults in three day-care centers. Participants in this experimental pretest posttest study that had a novel focus on tropical environment reported an increase in their cognitive functioning ($p < 0.05$)^[21].

Attention

Van den Bogerd investigated the effects of indoor biophilic design (potted plants and green wall) on the level of attention in classrooms^[7]. In this experimental study they conducted three longitudinal field experiment at a university, secondary school and secondary vocational school. The results suggested that only secondary students reported higher level of attention in the classroom with indoor nature in comparison with a classroom with the standard design (control), and self-reported attention in the other two studies did not find any meaningful differences between biophilic and non-biophilic classrooms. According to the authors the impact of biophilic design on students’ attention was likely to be influenced by many contextual factors^[7].

Executive Functioning

Kelz in a pre-post, quasi-experimental design with a multimethod approach investigated the effects of natural environment on the executive functioning in three middle schools in a rural area in Austria^[146]. Concerning their principal hypotheses were that the new design of the schoolyard would increase executive functioning, they did not find supporting result. They found that executive functioning enhanced from the pre- to the post-test that may be due to interfering effects like learning and school type. Moreover, the level of executive functioning reported by the experimental school was higher than that of reported by the control group at the measurement prior to the intervention. Greenery did not affect executive functioning as hypothesized.

Table 8. Cognitive performance and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Productivity	Workplace	Office workers, N=12 (males, N=10; females, N=2) Age: 25- 47 (male= 27-41; female= 25)	Experimental	Recycled planter box, Vegetable garden, Window view, Ventilation, Natural lighting, Bird's sound	Productivity= Increased	(Gray and Birrell, 2014) ^[13]
Course grade	Classrooms	Undergraduate students N=567 (male, N=284; female, N=283)	Quasi-Experimental	window view	Course grade=Increased, (Evaluation= course instructor report)	(Benfield et al., 2015) ^[15]
Creativity, Cognitive performance	Workplace	Knowledge workers N=64 (male, N=40; female=24) Age: Mean=41/6	Experimental	Integrating natural environments with the building	Creativity=Increased Cognitive performance=Increased	(Mangone et al., 2017) ^[14]
Intellectual performance, creativity	Workplace	College students N=8 (male, N=8)	Experimental	Natural lighting	Intellectual performance=Increased Creativity=Increased (Evaluation: Saliva analysis, heart rate, eardrum temperature, blood pressure)	(Ayuso Sanchez et al., 2018) ^[12]
Productivity, Cognitive performance	Utilitarian and hedonic services	Undergraduate business students, C.G.: N=60; Exp. G.: N=283 (male, N=237; female, n=46) Age, Exp. G. =18-44; C.G. =X>18)	Experimental	Greenery, Natural (wooden) finishes (for walls and floors), Natural lighting	Productivity= Increased, Cognitive performance= Increased (Method= MANCOVA)	(Purani and Kumar, 2018) ^[19]

Attention	Classroom	Study1: first-year Bachelor Biomedical Science students	Experimental	Interior plants (Coliseum species, Dracaena, Sansevieria, Dieffenbachia), Green walls, Potted plants	Attention= Increased (Evaluation=digit Symbol Substitution Test	(van den Bogerd et al., 2020) ^[7]
		N=70			(DSST) of the Wechsler Adult Intelligence Scale (WAIS))	
		(male, N=8; female, N=62)				
		Age: 18-24, Mean=19.5				
		Study2: Secondary school students				
		N=213				
		(male, N=101; female, N=112) Age: 12-18				
Mean= 14/53						
Study3: secondary vocational school students, N=161 (male, N=60; female, N=101), Age: 15-27						
Mean=17/8						
Cognitive performance	Therapeutic Garden	Elderly participants from three senior day care centers	Experimental	Horticultural based activities	Cognitive performance= Increased	(Sia et al., 2020) ^[21]
		N=47		Growing pea sprouts and vegetables, Setting up planters	(Evaluation= MMSE)	
		(male, N=14; female, N=33)				
		Age: 60-95				
Mean = 77.5						
Executive functioning	Schoolyard	School pupils, N=133 (male, N=68; female, n=65) Age, Exp.	Quasi-experimental	Shrubs, Potted plants, Drinking fountain	Executive functioning= No difference	(Kelz et al., 2015) ^[16]
		G. =14;			(Evaluation= The attention network test (ANT))	
		C.G. =14				
Exp. G.= Experimental Group, C.G.= Control Group						

Social Well-being

Two experimental studies examined the impacts of water, greenery, bird's sound, window view, natural lighting, non-synthetic material, ventilation on the level of individuals' social interaction and collaboration (Table 9)^[13, 20].

Social interaction

An experimental study suggested that the societal well-being and social interaction were affected by the biophilic elements integrated into the lifestyle center environment^[20]. The results revealed that the restorative potential of the green-version lifestyle center had a transformative role in increasing the societal well-being and social interaction compared to the control group.

Collaboration

In an experimental study Gray and Birrell examined the effect of biophilic design on the level of collaboration among staff in a workplace^[13]. The employees were supposed to be responsible for the construction of their personalized recycled planter box and choice of the plants. According to the interviews with the employees, their social capacity and collaboration reported by them highly increased after the transformation of their workplace to a biophilic site office.

Table 9. Social well-being and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Collaboration	Workplace	Office workers, N =12 (males, N=10; females, N =2) Age: 25- 47 (male= 27-41; female= 25)	Experimental	Recycled planter box, Vegetable garden, Window view, Ventilation, Natural lighting, Bird's sound	Collaboration = Increased	(Gray and Birrell, 2014) ^[13]

Social interaction	lifestyle center	<p>Study 1: private university students N=68 (male, N=38; female, N=30) Age: 17-41 Mean=23/91</p> <p>Study2: large private university students N=120 (male, N=65; female, N= 55) Age: 18-26 Mean= 18/76</p> <p>Study3: large private university students N=120 (male, N=53; female, N=67) Age: 19-53 Mean=23/39</p>	Experimental	Bird's sound, Natural elements, Water, Greenery	Social well-being=Increased (Method= MANOVA, ANOVA)	(Rosenbaum et al., 2018) ^[20]
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Nature Relatedness

In a quasi-experimental study Nisbet examined the correlation environmental education and the experiential relationship individuals have with the natural world or a subjective sense of connectedness with nature. Environmental courses held in the fall semester inspired students to re-evaluate their connection with nature that in turn leads to their well-being against the seasonal backdrop. Nisbet found that the level of ecological understanding and nature relatedness of students taking environmental courses is higher than that reported by the control group (Table 10) ^[17].

Table 10. Nature relatedness and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Nature relatedness, Ecological understanding	Classroom	Study1: Canadian undergraduate students N=184 (male, N=60; female, N=124) Age: Mean=19.48	Quasi-experimental	Environmental education	Nature relatedness= Increased	(Nisbet et al., 2011) ^[17]
		Study2: Federal government and private sector N=145 (male, N=58; female, N= 87) Age: 37-42			(Evaluation=Nature Relatedness Scale, five-point Likert scale)	
		Study3: Undergraduate students at a Canadian university Age: Mean=19/35				

Behavior

Several studies investigated the effects of water, greenery, bird's sound, natural lighting and window view on the people's behaviors including attendance in the classroom, consumer spending in life style centers and hotels, and their positive behaviors in hotels (Table 11) ^[7, 15, 18, 20].

Attendance

One study examined the attendance rate of undergraduate students in two classrooms one with a view of an open grassy area containing blossoming trees, and the other looking directly at a concrete retaining wall ^[15]. Regarding midterm and final attendance, results demonstrated that there was no statistically significant effect of visual access to natural environment on attendance.

Consumer Spending

Lee investigated the effects of indoor plants, water and natural lighting on consumers' intention to spend more money ^[18]. This experimental study exposed participants to real photos of hotels that had implemented biophilic elements in their built-in environment. The results of a series of t-tests revealed that the biophilic design did have significant main impact on consumer

spending. In the biophilic atmosphere consumers tended to spend more money than the control group or non-biophilic hotel lobby design. In another experimental study Rosenbaum exposed participants to a 1.20-min video that depicted a guided tour of a proposed lifestyle center to measure their level of consumer spending. They found that shoppers were encouraged to spend more money in a place where biophilic design elements existed.

Positive Behavior

In an experimental study Lee examined the impact of biophilic elements implemented in the hotel environment on the positive behavior using the photos and scenarios depicted a realistic encounter at an upper midscale hotel [18]. The findings of this study demonstrated that stronger positive behavioral response produced in the biophilic environments compared to the standard design.

Table 11. behavior and biophilic design.

Category	Setting	Participants	Study Design	Intervention	Outcome	Citation
Attendance	Classrooms	Undergraduate students N=567 (male, N=284; female, N=283)	Quasi-experimental	Window view	Attendance=NS (Evaluation= course instructor report)	(Benfield et al., 2015) [15]
Consumer spending	Lifestyle center	Study1: private university students N=68 (male, N=38; female, N=30) Age: 17-41 Mean=23/91 Study2: large private university students N=120 (male, N=65; female, N= 55) Age: 18-26 Mean= 18/76 Study3: large private university students N=120 (male, N=53; female, N=67) Age: 19-53 Mean=23/39	Experimental	Bird's sound, Natural elements, Water, Greenery	Consumer spending=Increased, (Evaluation= 7-point Likert-type scale, MANOVA, ANOVA)	(Rosenbaum et al., 2018)[20]
	Hotel (upper midscale)	Pilot study: Undergraduate students N= 36 (male, N= 9; female, N= 27) Age: 20-57 Mean= 24/97 Main study: N>91= have a college degree or higher N=246 (male, N= 152; female, N=94) Age: 44%=26-34, 22%=18-25, 19%= 35-44	Experimental	Plants, Water, Natural lighting	Customer perception of quality= Increased (Evaluation: 7-point Likert scale, ANOVA)	(Lee, 2019a)[18]

CONCLUSIONS and LIMITATIONS

The beneficial effects of exposure to nature have been researched most frequently, and two theoretical frameworks (attention restoration and biophilia theory) offer explanations of these positive impacts. The findings of several empirical studies have collectively demonstrated that different appearances of nature such as nature views, water, sounds' birds, sky view, indoor plants, non-synthetic materials, natural lighting, ventilation and images of nature are related to preferable psychological outcomes, including reduced stress, anxiety, workload perception, mental fatigue as well as improved productivity, attention, social well-being, collaboration, cognitive performance and positive mood. Experimental studies found that people perceive the restorative potential of biophilic design in places where natural elements existed.

The findings of this study have revealed that implementing biophilic design in businesses such as life style centers and hotels enhances guest emotional responses, consumers' attention and mood, thus making consumers more relaxed, and happy that also encourages more consumption and spending. These empirical studies provide useful information for stakeholders such as owners and managers to differentiate their services from their competitors using biophilic elements [18, 20]. According to several studies integrating nature in educational settings leads to improved academic performances, positive perception of course materials, overall mood, mental well-being and better ecological understanding and stress reduction [1, 7, 15, 16]. Some experimental studies focused exclusively on the role of biophilic design in workspaces. They found that exposing to natural elements can have positive effects on increasing the level of productivity, collaboration, creativity and mental well-being among employees and decreasing the level of their stress and anxiety as well [12-14, 19, 24].

There are several limitations that should be discussed. The first limitation would be that most of the experimental studies have focused on the participants' responses to green or non-green places. Thus, this review still lacks an insight of the certain types of biophilic elements that provoke a positive behavior. In other words, future researches are needed to examine specific types of plants, forms of water, or the presence of natural lighting may encourage more positive behavior than the other elements. The second limitation is that the number of papers examining the effects of biophilic design in areas such as prisons, drug rehabilitation centers and mental health rehabilitation center are very rare, so future experimental researches in those areas would have been recommended. Third, this review paper includes only experimental and quasi-experimental studies, and the other studies such as literature reviews, qualitative studied and expert opinions have been excluded.

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