Effects of biophilic design on sustainable behaviors: introducing the use of serious game as a measure of sustainable behavior

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Abstract

Purpose – This study explores the impact of biophilic design in built environments on sustainable behaviors through the innovative use of a serious game. By examining how exposure to biophilic elements influences behaviors in real and virtual settings, the research aims to demonstrate the potential of serious games as tools for promoting sustainability.

Design/methodology/approach – The study was conducted in three distinct experimental settings: (1) a real environment pre-game, (2) a non-immersive game environment within the same real setting and (3) an immersive game environment post-game. Data were collected from 162 participants who experienced these different conditions. The serious game "Pop a Coffee Corner" was developed based on biophilic design principles and used to assess behavioral changes.

Findings – Results indicated that exposure to biophilic design elements in real settings significantly enhanced sustainable behaviors compared to non-biophilic environments. Additionally, playing the serious game in a biophilic environment led to even greater improvements in sustainable behavior than exposure to biophilic design alone. This demonstrates the effectiveness of serious games in fostering sustainable actions.

Research limitations/implications – The study's findings are based on a specific university setting, which may limit generalizability. Future research could explore long-term impacts and applications in diverse contexts.

Practical implications – The research provides practical guidelines for incorporating biophilic design in built environments, and developing serious games can be a practical strategy for architects, urban planners and educators to promote sustainable behaviors among individuals. This approach can be applied in educational settings, public spaces and workplaces to foster a deeper connection with nature and encourage environmentally responsible behaviors.

Social implications – By demonstrating the effectiveness of biophilic design and serious games in promoting sustainable behaviors, this study contributes to broader societal efforts to address environmental

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challenges. Implementing these strategies can lead to increased environmental awareness and pro-environmental behaviors, ultimately supporting sustainability goals.

Originality/value – This study introduces the serious game approach as a novel method to evaluate and promote sustainable behaviors through biophilic design. It highlights the potential for integrating biophilic elements in both real and virtual environments to encourage environmentally responsible behavior, offering valuable insights to architects, designers and policymakers.

Keywords Sustainable behavior, Biophilic design, Serious games, Virtual reality

Paper type Research paper

1. Introduction

The rapid increase in industrial production, high levels of consumption and disregard for nature resulted in climate change and ecological disasters driven by environmentally inconsiderate behaviors. Environmental degradation is a problem where the actions of individuals can have significant negative impacts on the environment. A phenomenon known as the "commons dilemma" (Hardin, 1968) is challenging to address, but research is ongoing. Humans' disconnection from nature, spending most of their lives in built environments, contributes to negative environmental attitudes (Nisbet *et al.*, 2009). In built environments, sustainable design solutions have been used to create environmentally responsible architecture, but this is not the only solution (Kellert, 2008). While current sustainable design acknowledges the need for diversity in building and design, it focuses primarily on reducing environmental impacts (Kellert, 2008). However, when sustainable design is approached independently, it often ignores the importance of achieving long-term sustainability (Kellert, 2008). This approach fails to reconstruct humans' relationships with nature and promotes a mutually beneficial attitude in the built environment. Solutions such as a biophilic approach are needed to create environments. This approach is defined as a design method that integrates elements of the natural environment into the built environment through specific design criteria (Kellert, 2008). Application of this approach in design fields encourages individuals to be environmentally responsible and fosters positive changes in their attitudes and behaviors (Wijesooriya and Brambilla, 2021).

Tools such as computers, virtual reality (VR), augmented reality, mixed reality and serious games can help people experience designed environments. The literature supports the use of biophilic design in this context, as it has been shown to positively affect users' moods, knowledge and behavior (Browning and Ryan, 2020; Wijesooriya and Brambilla, 2021; Zhong *et al.*, 2022; Bilgic and Ebbini, 2023). Studies showed that exposure to natural elements in immersive VR reduced negative moods to the same extent as exposure to natural elements in a built environment (Emamjomeh *et al.*, 2020; Yin *et al.*, 2018).

The serious game concept is critical to changing behavior (Schuller *et al.*, 2013). It has been used to test, change or determine human behavior (Aldrich, 2009; Tobler-Ammann *et al.*, 2017). Recent studies have shown that serious games, which aim to address environmental issues, have positive effects on users' cognitive outcomes, experiences, knowledge, learning and behavior (Özgen *et al.*, 2020; Connolly *et al.*, 2012; Johnson *et al.*, 2017; Senbel *et al.*, 2014; De Vries and Knol, 2011). Further research is needed to explore the effects of biophilic design on sustainable behaviors through serious games. Understanding how these digital tools can create environments and change individuals' attitudes toward the environment is critical.

2. Objectives of the study

This research aims to promote sustainable behaviors through a biophilic environment via serious games. It introduces the serious game concept as a new tool to evaluate the impact of exposure in the biophilic environment on sustainable behaviors. The study is framed around three research questions:

RQ1. Is there any difference between exposure to biophilic and non-biophilic environments in real settings regarding sustainable behaviors?

RQ2. Does playing a serious game with biophilic design elements in a biophilic environment change sustainable behaviors compared to a biophilic built environment?

RQ3. What are the contrasting sustainable behaviors observed in real-world settings versus virtual reality environments?

The research involves three studies and three hypotheses:

H1. There is a statistically significant difference between the control group (experiencing the non-biophilic built environment) and the treatment group (experiencing the built environment with biophilic design) regarding sustainable behaviors.

H2. Participants who engage in a serious game incorporating biophilic design elements exhibit more substantial improvements in sustainable behaviors than those who only interact with the actual built environment.

H3. Participants exhibit distinct sustainable behaviors in a virtual reality environment compared to real-world settings.

3. Literature review

3.1 Biophilic design and its relation to sustainable behaviors

Biophilic design is used in architecture and design to connect people with nature, making them feel more connected and improving their well-being. This approach is achieved by using natural elements such as plants and natural light and designing spaces that mimic nature. Biophilic design can be used in both individual buildings and entire cities and has been shown to have numerous benefits, such as reducing stress, promoting creativity and mental clarity and improving overall well-being (Browning *et al.*, 2014; Kellert and Wilson, 1993; Kellert *et al.*, 2008; Kellert, 2008, 2015). Salingaros (2019) and McGee *et al.* (2022) developed biophilic indexes to assist designers to create biophilic built environments. These indexes may help to satisfy users after implementing the biophilic design features (Shakhshir and Sheta, 2023).

As the global population becomes increasingly urbanized, the importance of biophilic design grows. This growth has led to Browning *et al.* (2014) categorizing biophilic design patterns into 14 items under three headings: *nature in the space*, *natural analogues* and *nature of the space*. These design patterns aim to improve the connection between humans and nature and to change the human experience (Ergan *et al.*, 2019). Studies in the human–nature context have shown that contact with nature increases pro-environmental attitudes in children and youth (Collado and Corraliza, 2013; Hartig *et al.*, 2001). Browning *et al.* (2014, p. 3) explain the connection between nature, human biology and the design of the built environment and how this approach can be applied to design projects to achieve the positive effects of biophilia.

The current process of built environment design is a tectonic expression of architecture that relies on the abstraction and popularization of physical separation from nature (Salingaros and Masden, 2008). This separation leads to unsustainable behaviors (Ives *et al.*, 2018). However, sustainable behaviors are necessary to overcome natural disasters, global warming, climate change and biodiversity loss. The shift from a natural environment to a built environment in industrialized societies has resulted in a significant separation from nature and has contributed to unsustainable energy use, biodiversity loss, pollution, contamination, climate change, global warming, etc. The authors think that fundamental design flaws play an essential role in this alienation from nature and can be addressed by harmonizing with nature in the built environment (Kellert, 2008).

Biophilic design can potentially change human behavior as an opportunity (Africa *et al.*, 2019; Fink, 2011; Whitburn *et al.*, 2019), indicating that it promotes pro-environmental behaviors and relates to increasing environmental awareness. Tucker and Izadpanahi (2017) showed that designed buildings connected to the natural world make participants significantly more pro-environmental. Therefore, creating biophilic buildings or designing solutions with nature connections encourages sustainable behaviors. Wijesooriya and Brambilla (2021) reviewed the biophilic literature and investigated biophilic design's potential strengths, weaknesses, opportunities and threats within the built environment. However, their study (2021) indicated that biophilic design research lacks a framework. Ryan *et al.* (2014) stated that, some elements of biophilia are intrinsically challenging to measure, and given the relatively early stage of biophilic design as a field, it is clear that further research is crucial.

Engaging in actions aimed at caring for others and simultaneously protecting the biophysical environment are the requirements of sustainable behavior (Bonnes and Bonaiuto, 2002). A sustainable lifestyle seeks to create environmentally significant behaviors, which can be defined by their impact on the ecosystem's materials, energy or dynamics (Stern, 2000). Therefore, these behaviors are based on human decision-making and intend to change the environment (Stern, 2000). These behaviors and decision-making are the processes of consumption actions in this frame. Consumption is often understood as a consequence of decision-making concerning environmentally significant behavior (Corral-Verdugo *et al.*, 2014; Stern, 1997). Decision-making is part of cognitive functioning and can be divided into sustainable and environmentally concerned behavior types: one-time actions and repetitive actions (McKenzie-Mohr, 2000). Decision-making is choosing one option from multiple competing alternatives (Jin *et al.*, 2019; Peters *et al.*, 2011). This process involves various steps, including information seeking, comparing alternatives, choosing an option and finding the outcome. The decision-making process is influenced by the characteristics of the situation and the individual decision-maker (Stern, 2000).

3.2 Serious games and behavior

Serious games aim to influence human behavior, cognition or attitudes through well-designed digital games (Johnson *et al.*, 2017). These games go beyond entertainment, offering interactive computer-based experiences that educate and motivate users (Ritterfeld *et al.*, 2009, p. 4). They are widely used in fields like healthcare, cognitive skills training and learning (Primack *et al.*, 2012; Parong *et al.*, 2017; Connolly *et al.*, 2012), often integrating aspects of simulation with elements of fun and competition (Plass *et al.*, 2018).

Research has explored how serious games can promote sustainable behaviors such as energy conservation, recycling and reducing consumption. For instance, games like "EnerCities" and "EnergyLife" demonstrated significant increases in energy-saving attitudes and behaviors (De Vries and Knol, 2011; Gamberini *et al.*, 2001). However, not all games show the same impact; "EcoIsland," for example, did not influence energy-saving motivation (Kimura and Nakajima, 2011). A review of serious game studies highlighted their positive effects on behavior, cognition, learning and user experience in sustainability contexts (Johnson *et al.*, 2017). While some studies suggest potential adverse effects on environmental attitudes (Gustafsson *et al.*, 2009), others show promising results in enhancing pro-environmental awareness (Özgen *et al.*, 2020). Theoretical frameworks like the theory of planned behavior, self-determination theory and cognitive-behavioral theory help explain how serious games can influence attitudes, beliefs and behaviors by shaping behavioral intentions and perceived control (Ajzen, 1991; Deci and Ryan, 1985; Beck, 1976). The key aspects of serious games that promote sustainable behaviors include game mechanics, goal-oriented gameplay and decision-making scenarios (Deterding *et al.*, 2011; Erhel and

Jamet, 2016; Hainey *et al.*, 2016). These elements encourage players to behave environmentally in a controlled virtual environment.

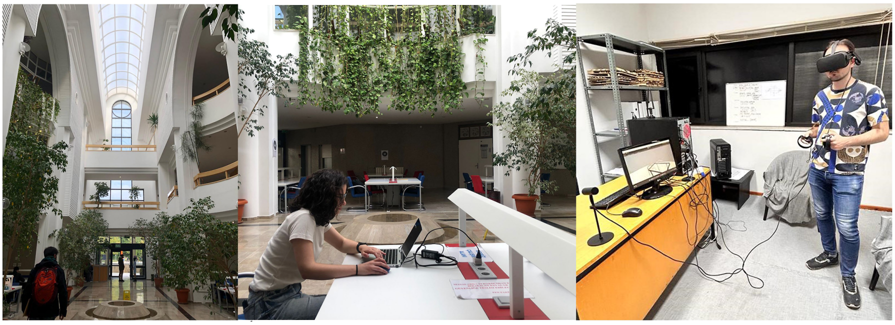
4. Method

4.1 Settings and the participants

This study was conducted in three different settings, and four corresponding data sets were collected. The settings were as follows: Study Set 1 (Figure 1a) occurred within the science building (Building A) of a university campus spanning 5,000 acres, with 3,000 acres designated as forested areas. Study Set 2 (Figure 1b) was conducted in a non-immersive computer environment within the same building as Study Set 1. Study Set 3 (Figure 1c) took place in an immersive VR environment designed and created by the first author. Additionally, a controlled experiment study aimed to gather data from a controlled group in another building (Building B) of the same university. Building B was chosen due to its architectural similarity to Building A, but with a distinct lack of biophilic design elements.

The selection of Building A as the physical setting for the experiment was based on its high score of 43 out of 54 on the biophilic interior design index (BIDI) (Yin *et al.*, 2018; Ryan *et al.*, 2014). This score was determined by four architects, each possessing approximately 15 years of experience in sustainable design. Similarly, Building B was chosen for the controlled experiment due to its lower BIDI score of 15 out of 54 (Yin *et al.*, 2018; Ryan *et al.*, 2014). Before commencing data collection, we designed the experiment using G*Power to calculate the required sample size (Faul *et al.*, 2009). With a medium effect size ($f = 0.25$), $\alpha = 0.05$, and power $(1-\beta) = 0.95$, the calculation indicated a necessary sample size of approximately 43 participants per group, totaling 172 participants. Subsequently, ethical permissions were obtained from the university's ethics council, and data were collected from 173 participants. However, 11 participants were excluded from the study for not meeting the research criteria, resulting in data analysis being conducted on 162 participants. The sample size varied slightly across groups, ranging from 40 to 43 participants. Previous studies on serious games in decision-making contexts have reported participant numbers ranging from 15 to 189 (Linehan *et al.*, 2009; Ong and Araral, 2021; Roungas *et al.*, 2020).

Data collection occurred between 12:00 p.m. and 4:00 p.m. on weekdays to maximize natural daylight, excluding days with overcast weather. Williamson and Cummins (1983) have defined 1,000 lux as an overcast day and above 10,700 lux as daylight. Using this information, we conducted measurements on the days of our experiment with the Light



(a) **(b)** **(c)**

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Figure 1. (a) Setting 1, Building A's entrance hall, (b) Setting 2, Building A's study area, (c) Setting 3, virtual reality experiment area

Meter LM-3000 application. This app was developed and tested by optics scientists and engineers, and it was calibrated for all iPhones and iPads using professional equipment, as stated by the developer. We did not conduct experiments on days of daylight below 1,000 lux. Our daylight measurements were generally around 14,000 lux on the days we conducted experiments.

4.2 Experimental procedures

The experimental procedures of this research encompassed four distinct stages or datasets. Firstly, in Study Set 1, the grounded theory (Glaser *et al.*, 1968) was used to create a serious game design framework. The focus was on analyzing participants' perceptions of natural environments, specifically their views on sustainable behavior and biophilic design. Participants experienced Building A's interior space and completed questionnaires for us to capture their perceptions of various biophilic design elements. The findings from Study Set 1 were crucial in developing the framework for the subsequent stages of the research.

Following Study Set 1, Study Set 2 centered on developing and implementing a serious game based on the framework derived from the pre-game stage. This game aimed to explore how biophilic design elements could influence human behavior. Participants engaged with the serious game and completed sustainable behavior tests, providing data on the game's effectiveness in promoting sustainable behaviors.

In Study Set 3, researchers focused on evaluating the impact of environmental settings – both VR and physical environments – on the configuration of the biophilic serious game. Participants played the game in both VR and physical environments, allowing researchers to compare behavioral changes across different settings and further understand the game's influence on sustainable behavior.

Lastly, a controlled experimental stage was conducted in Building B on the same university campus. Building B was chosen as a controlled environment for Building A due to its similarities in function, design language and material use while differing in biophilic design elements. This choice aimed to ensure similar representations of indoor spaces and evoke the same sense of natural space hierarchy (Richter *et al.*, 2011).

Overall, these four datasets formed a comprehensive experimental approach to investigating the effects of biophilic design elements on human behavior, encompassing both virtual and physical environments for a holistic understanding of the research outcomes.

4.2.1 Study 1: pre-game procedure. Study 1 aimed to establish a foundational understanding of how biophilic design influences user behavior and interaction. To achieve this, we employed grounded theory, which systematically analyzes an individual's subjective perception of the biophilic design. This preliminary phase was crucial for framing the development of the subsequent serious game. The procedure was as follows: First, participants were recruited to ensure a diverse representation of perspectives on biophilic design. They were invited to engage in Building A, chosen for its varied biophilic design elements. Then, they completed a structured questionnaire to capture their perceptions and reactions to different biophilic design elements in the building environment. Afterward, they participated in semi-structured interviews. These interviews allowed for an in-depth exploration of individual perceptions and attitudes toward sustainable behavior and biophilic design. Finally, the data collected from the questionnaires and interviews were analyzed to identify key themes and patterns related to biophilic design and sustainable behavior. This analysis developed a conceptual framework that guided the design and implementation of the serious game in Study 2.

4.2.2 Study Set 2: game procedure. This study focused on investigating how the game environment affects user behavior. The results from the first study were used to develop a biophilic design framework for the game. The game was designed to incorporate the biophilic design elements found to be the most relatable and perceivable by participants, such as visual connection with nature, dynamic and diffuse light, the presence of water and mystery elements.

The study compared the effects of real and non-immersive virtual environments on participants' sustainable behaviors while playing the game. The sample groups were divided into two: one group filled out questionnaires without playing the game, while the other group filled out the same questionnaires after playing the game.

4.2.2.1 Game design. The game "Pop a Coffee Corner" was divided into two main parts. Initially, players made decisions, followed by designing a coffee corner. This game aimed to address sustainability issues in the coffee industry, including coffee cup waste, transportation impact, CO_2 emissions and rainforest depletion.

Players used 22 items to design the coffee corner, such as bags, cups, various coffee beverages, tables and chairs. The gameplay included challenges like time constraints, item selection at the entrance, decision-making and placing items within the coffee corner, adding complexity to the game. Structured as a clicker game, players had two minutes to make decisions and earn points. During gameplay, chosen items were stored in an inventory bag (Figure 2) and could be placed in the coffee corner after the designated time.

4.2.3 Study Set 3: post-game procedure. Study Set 3 compared real and virtual environments for potential behavioral changes. This part of the study employed between-subject designs. Participants engaged in tasks within a virtual reality (VR) environment while playing the serious game "Pop a Coffee Corner," which featured biophilic design elements. After completing the gameplay process, we obtained the outcomes regarding the participants' sustainable behaviors from the game. The collected data underwent analysis to discern any correlations, associations or differences between groups.

4.2.4 Controlled experimental stage. In this stage, a control group experiment was conducted to determine whether a significant difference existed between the experimental and control groups. Participants from Building B completed the sustainable behavior scale (SBS) questionnaire in the indoor space of the same building. Subsequently, the collected data were compared to other experimental groups' data.

4.3 Instruments and tools

Clayton (2003) argues that environmental identity, supporting universal values, environmental behaviors and environmental decision-making, can vary between cultures. Clayton and Kilinç (2013) adapted the environmental identity and pro-environmental behavior scale for participants' nationality, which was utilized in this study. A total of 24 items on environmental identity and pro-environmental behaviors were included. Sustainable consumption behavior (SCB) is increasingly concerning due to its environmental impact (Bhamra *et al.*, 2011). Quoquab *et al.* (2019) developed a reliable 24-item SCB scale to understand users' sustainable behaviors, which was adopted in this study. Ajzen (1991) posited that three constructs shape human behavior: behavioral, normative and control beliefs. The perception of behavioral control influences the effects of behavioral attitude and subjective norms on intention. Self-assessment interview questions from Ajzen's (1991) theory of planned behavior question construction were adopted to understand participants' perceptions.

This study employed four instruments to gauge participants' responses: the environmental identity and pro-environmental behavior scale (Clayton and Kilinç, 2013), the SCB scale (Quoquab *et al.*, 2019) and the theory of planned behavior question construction scale (Ajzen, 1991). To ensure clarity and accuracy, these instruments were translated from English to their native language and back to English.

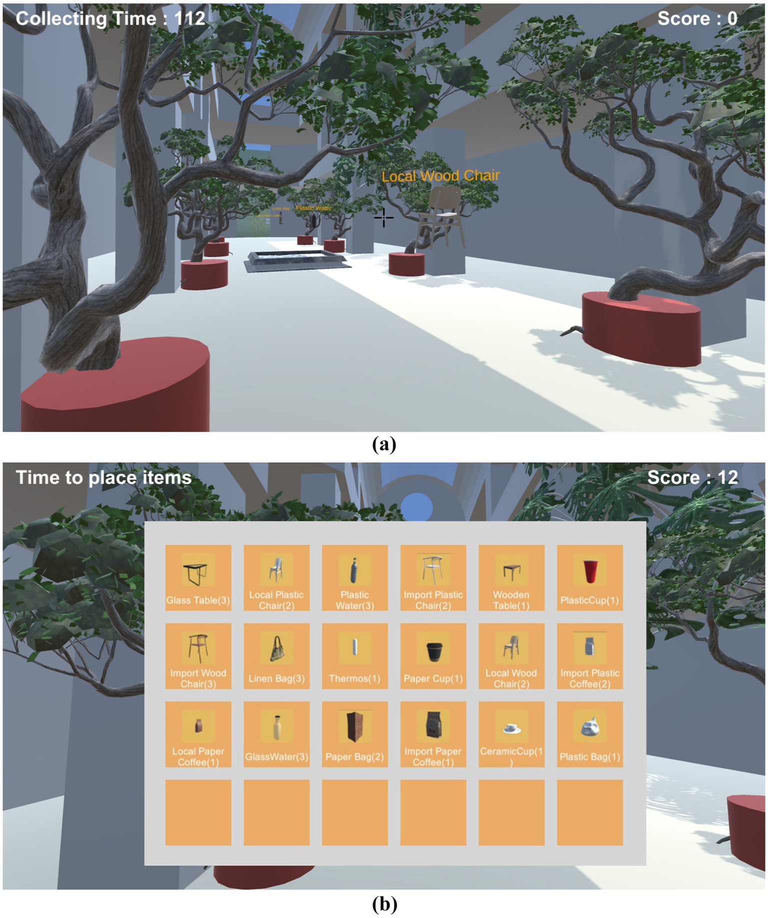

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Figure 2.
(a) Game screen, (b) Inventory screen

In this research, a serious game was developed using the unity game engine, while the VR environment was experienced via HTC Vive headsets. Blender 3.6 was used for 3D modeling aspects. Statistical data analysis was conducted using JASP 0.16.2.

5. Results

5.1 Study Set 1: pre-game findings

We analyzed the collected data through statistical methods. Within dataset 1, we coded the dimensions and identified 14 distinct biophilic design elements (Table 1).

The data were coded into JASP version 0.16.2 for network analysis. The results are presented in Table 2 and Figure 3. Table 2 provides a summary of the network analysis. Each node in Figure 3 represents a biophilic design item, and the connections indicate their relationships. The thickness of the connection reflects the strength of the association. Blue connections represent positive associations, while red connections represent negative

Item category	Item number	Item name
Nature in the space (NIS1)	1	Visual connection with nature
Nature in the space (NIS2)	2	Non-visual connection with nature
Nature in the space (NIS3)	3	Non-rhythmic sensory stimuli
Nature in the space (NIS4)	4	Thermal and airflow variability
Nature in the space (NIS5)	5	Presence of water
Nature in the space (NIS6)	6	Dynamic and diffuse light
Nature in the space (NIS7)	7	Connection with natural systems
Natural analogues pattern (NA1)	8	Biomorphic forms and patterns
Natural analogues pattern (NA2)	9	Material connection with nature
Natural analogues pattern (NA3)	10	Complexity and order
Nature of the space patterns (NOF1)	11	Prospect
Nature of the space patterns (NOF2)	12	Refuge
Nature of the space patterns (NOF3a/b)	13	Mystery
Nature of the space patterns (NOF4a/b)	14	Risk/peril

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Table 1. Abbreviation list of 14 biophilic items

Number of nodes	Number of non-zero edges	Sparsity
16	120/120	0.000

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Table 2. Summary of network analysis

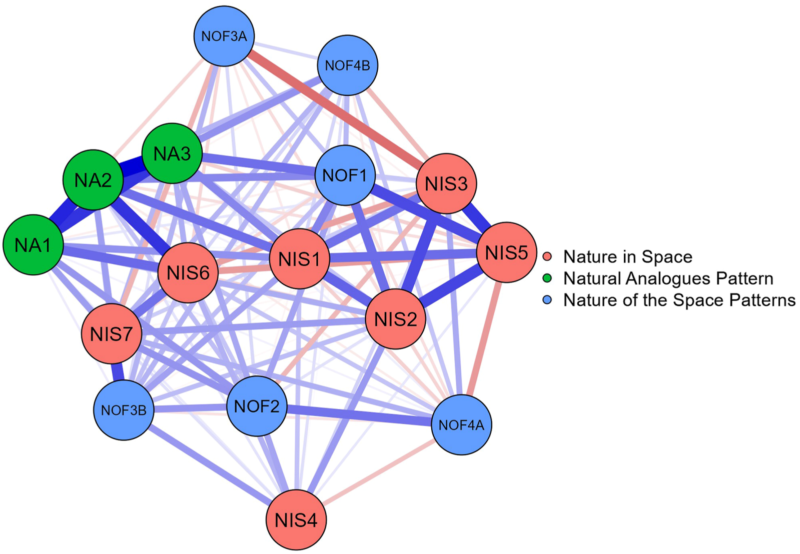

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Figure 3. Network analysis diagram of biophilic design items

associations. The centrality plot reveals the highest betweenness measures, which include visual connection with nature (NIS1), non-rhythmic sensory stimuli (NIS3), non-visual connection with nature (NIS2) and presence of water (NIS5) (Figure 4).

We conducted a semi-structured interview with 20 participants (11 women and nine men) and analyzed interview items (1- What do you know about sustainable behaviors? 2- How do you perceive sustainable behavior? 3- Do you agree with the definition of sustainable behavior above? Yes or No, please explain why. 4- Do you think exposing biophilic design items in the building can change your attitude towards nature? Yes or No. Please explain why. 5- How do you relate the biophilic design items of this building with your sustainable behaviors? 6- How do you evaluate yourself regarding environmentally caring actions? 7- What are the future advantages of working in the building? 8- What are the disadvantages of working in the building next time?). Additionally, participants provided ratings for the building's design elements that promote sustainable behavior using a seven-point Likert scale (Which design elements of this building would encourage sustainable behaviors?). Visual connection with nature (item 1, score 57) and dynamic and diffuse light (item 6, score 25) obtained the highest scores.

The analysis led us to determine that non-rhythmic sensory stimuli, dynamic and diffuse light, visual connection with nature, non-visual connection with nature and the presence of water are the main elements that serve as the foundational components for the serious game design framework in the Study Set 2 (Figure 5). We structured the framework into four categories: physical, visible, non-visible and noticeable. Spatial arrangements like openings and layering were essential to embody these categories within the environment. Structural partitions such as windows, doors, the structure itself and objects are required for the biophilic design to be applied to the environment.

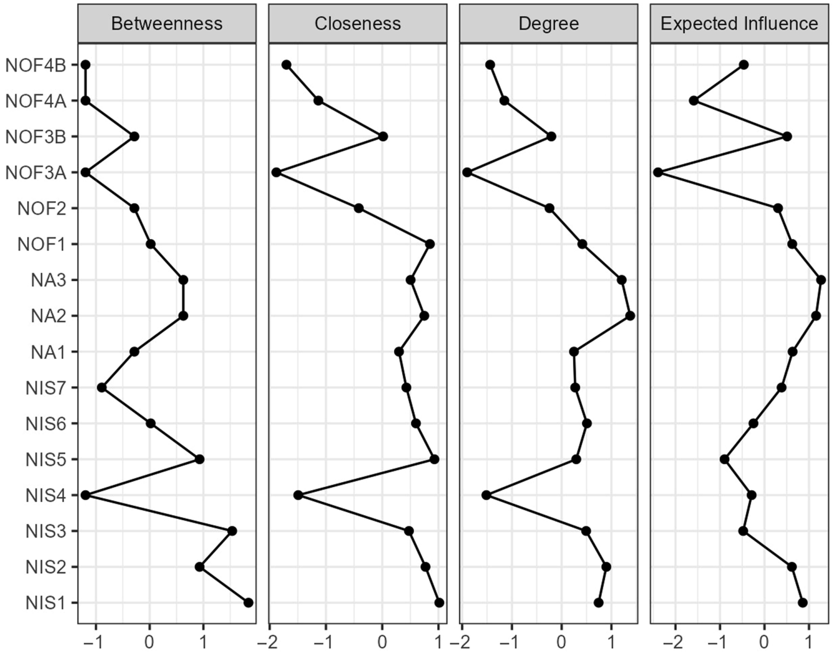

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Figure 4.
Centrality plot graph

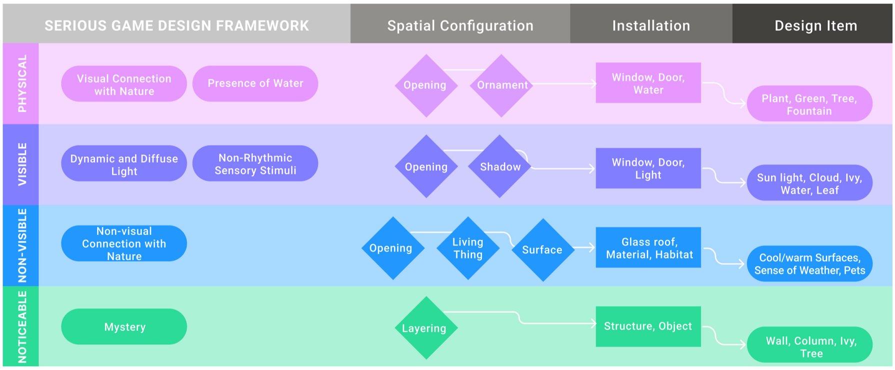

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Figure 5.
Design framework of the game

5.2 Study Set 2: game findings

In this section, experimental groups were categorized into four: Group 0; control group, Group 1; only biophilic treatment exposure group, Group 2; game players in a real environment with a biophilic treatment exposure group and Group 3; Game players in a VR environment with a biophilic treatment exposure group. Descriptive statistics were conducted after that. Initially, Group 0 and Group 1 were analyzed to test H1, followed by the analysis of Group 1 and Group 2 to test H2. Descriptive statistics indicated that Group 0 and Group 1 were normally distributed, as per the Shapiro–Wilk test results in Table 3.

After conducting descriptive statistics to test hypothesis H1, which posits a statistically significant difference between the control group (experiencing the non-biophilic built environment) and the treatment group (experiencing the built environment with biophilic design) in terms of sustainable behaviors, an independent sample *t*-test was performed. The results revealed a statistically significant difference between Group 0 and Group 1 concerning the SBS (Student's *t*-test $p < 0.041$). However, no significant difference was observed between the groups regarding the subcategories of the SBS (see Table 4). Therefore, H1 is supported.

Furthermore, descriptive statistics (refer to Table 3) were calculated to test the normality of Group 1 and Group 2. The Shapiro–Wilk test results in Table 3 demonstrate that all subcategories of the SBS were normally distributed (quality of life: Group 1 $p = 0.52$, Group 2 $p = 0.22$; care environmental well-being: Group 1 $p = 0.15$, Group 2 $p = 0.06$; environmental identity: Group 1 $p = 0.46$, Group 2 $p = 0.0454$; pro-environmental behavior: Group 1 $p = 0.39$, Group 2 $p = 0.87$).

Following descriptive statistics, to test hypothesis H2, an independent sample *t*-test was conducted. The results indicated a significant difference between Group 1 and Group 2 regarding SCB (quality of life: student's *t*-test $p = 0.028$), environmental identity (student's *t*-test $p < 0.001$), pro-environmental behavior (student's *t*-test $p = 0.009$) and SBS (student's *t*-test $p = 0.022$). The significance and non-significance of the *p*-values can be viewed in Table 4. These findings support the claim that playing a serious game with biophilic design elements leads to a more significant increase in participants' sustainable behaviors than merely experiencing the built environment; therefore, H2 is supported.

5.3 Study Set 3: post-game findings

The SBS exhibited acceptable consistency with all items and sub-categories ($\alpha = 0.85$), and an alpha level of 0.05 was utilized for all statistical tests. ANOVA was employed to compare

Table 3. Descriptive statistics of Group 0, Group 1 and Group 2

	QualityofLife			CareEnvWellbeing			EnvIdentity			ProEnBeh			SBS		
Groups	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
Valid	41	42	40	41	42	40	41	26	40	41	26	40	41	43	40
Missing	0	1	0	0	1	0	0	17	0	0	17	0	0	0	0
Mean	3.86	4.03	4.21	3.81	3.89	4.05	5.23	5.09	5.91	3.51	3.5	3.81	3.69	3.85	4.02
Std. Dev	0.57	0.44	0.39	0.64	0.66	0.6	0.92	1.04	0.66	0.54	0.5	0.52	0.48	0.37	0.35
Skewness	−0.45	−0.13	−0.15	−0.78	−0.24	−0.72	−0.71	0.31	−0.86	−0.17	0.45	−0.06	−0.26	0.42	0.2
Std. Err. of Skewness	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.46	0.37	0.37	0.46	0.37	0.37	0.36	0.37
Kurtosis	−0.61	−0.67	−0.91	0.39	−0.84	0.36	−0.6	−0.61	0.95	−0.62	−0.51	−0.46	−0.9	−0.29	−0.16
Std. Err. of Kurtosis	0.72	0.72	0.73	0.72	0.72	0.73	0.72	0.89	0.73	0.72	0.89	0.73	0.72	0.71	0.73
Shapiro–Wilk	0.95	0.98	0.96	0.95	0.96	0.95	0.98	0.96	0.94	0.98	0.96	0.99	0.96	0.96	0.98
p-value of Shapiro–Wilk	0.09	0.52	0.22	0.07	0.15	0.06	0.53	0.46	0.04	0.57	0.39	0.87	0.11	0.18	0.7
Min	2.7	3	3.5	2.2	2.6	2.3	3.2	3.2	4	2.3	2.6	2.7	2.7	3.2	3.3
Max	4.9	4.9	4.9	4.9	4.9	4.9	7	7	7	4.5	4.6	4.9	4.5	4.7	4.9

Note(s): 0: Group 0, 1: Group 1, 2: Group 2
QualityofLife: quality of life is the sub-category of the sustainable consumption behavior scale, CareEnvWellbeing: care environmental well-being is the sub-category of the sustainable consumption behavior scale, EnvIdentity: environmental identity, ProEnvBeh: pro-environmental behavior
Significant results suggest a deviation from normality
*$p < 0.05$
Source(s): Table created by authors

	t	df	p
Group 0 and Group 1			
SBS	−1.764	82	0.041*
QualityofLife	−1.460	81	0.074
CareEnvWellbeing	−0.584	81	0.280
EnvIdentity	0.544	65	0.706
ProEnvBeh	0.053	65	0.521
Group 1 and Group 2			
SBS	−2.054	81	0.022*
QualityofLife	−1.947	80	0.028*
CareEnvWellbeing	−1.153	80	0.126
EnvIdentity	−3.902	64	<0.001**
ProEnvBeh	−2.408	64	0.009*

Note(s): QualityofLife: quality of life is the sub-category of the sustainable consumption behavior scale, CareEnvWellbeing: care environmental well-being is the sub-category of the sustainable consumption behavior
The alternative hypothesis specifies that Group 0 is less than Group 1 for all tests
The alternative hypothesis specifies that Group 1 is less than Group 2 for all tests
Source(s): Table created by authors

Table 4. Summary of Group 0 – Group 1, and Group 1 – Group 2 comparisons

the mean scores among Group 1, Group 2 and Group 3. Effect size values, represented by Eta-squared values, are provided in the table for the scores exhibiting statistically significant differences between the groups.

ANOVA coefficient,

Sum of squares between groups $= \sum (\sum X_i)^2/n_i - (\sum X_i)^2/N$

Where:

X_i = Individual scores in each group

n_i = Number of scores in each group

N = Total number of scores.

Post-hoc analyses were conducted using the Bonferroni test for scores identified with significant differences among the groups, and Table 5 includes information on which specific groups contributed to these differences. The mean scores for care environmental well-being (CareEnvWellbeing) among the groups displayed statistically significant differences ($p = 0.027 < 0.05$). This difference primarily arises from variations between Group 2 and Group 3, indicating that distinct biophilic designs significantly influence the CareEnvWellbeing score ($p = 0.024 < 0.05$).

ANOVA results indicate statistically significant differences in environmental identity (EnvIdentity) mean scores among the groups ($p < 0.001$). Subsequent *post-hoc* analyses reveal that Group 1 significantly differs from both Group 2 and Group 3 concerning this score, suggesting that gaming behavior impacts this score, as Group 1 participants, who do not engage in gaming, exhibit lower EnvIdentity scores compared to Group 2 and Group 3.

Regarding the pro-environmental behavior (ProEnvBeh) score comparison among the groups, significant differences were detected ($p = 0.036 < 0.05$). Further *post-hoc* analysis unveils a statistically significant difference, specifically between Group 1 and Group 2, concerning the ProEnvBeh score ($p = 0.030 < 0.05$).

The statistical analysis above supports H2 but indicates that H3 is rejected.

Pearson's correlation test demonstrated the relationship between SBS and game score or unsustainable-sustainable decisions within Group 2 and Group 3. The statistics indicated no

Group	Mean	Std. deviation	Eta-square	*F*	*p*
SBS					
Group 1	3.82	0.37			
Group 2	4.02	0.35	–	1,975	0.143
Group 3	3.92	0.40			
CareEnvWellbeing					
Group 1	4.03	0.69			
Group 2	4.05	0.60	0.058	3,715	0.027*
Group 3	3.65	0.77			
Group 2 - Group 3					*0.024**
QualityofLife					
Group 1	4.12	0.43			
Group 2	4.21	0.39	–	1,763	0.176
Group 3	4.13	0.47			
EnvIdentity					
Group 1	5.1	1.05			
Group 2	5.91	0.66	0.137	8,311	<0.001**
Group 3	5.65	0.74			
Group 1 - Group 2					*<0.001***
Group 1- Group 3					*0.018**
ProEnvBeh					
Group 1	3.5	0.51			
Group 2	3.81	0.52	0.062	3,445	0.036*
Group 3	3.7	0.40			
Group 1 - Group 2					*0.030**

Note(s): 95% confidence interval, $*p < 0.05$, $**p < 0.001$
Source(s): Table created by authors

Table 5. Summary of ANOVA tests

significant correlation between game scores ($p = 0.342$), unsustainable ($p = 0.121$) and sustainable choices ($p = 0.958$) and the SBS ($p = 0.435$) scores of the participants.

6. Discussion

Scientific studies emphasize the environment's influence on sustainable behaviors, particularly within built environments. Since a significant portion of our daily lives takes place within the built environments, the impact of these environments on our behaviors is inevitable. In this context, biophilic design is key to shaping these behaviors, while serious games have emerged as a research tool to analyze them. This study employed the serious game approach as a novel measurement tool to comprehend and analyze individuals' sustainable behaviors.

Four experiments tested three hypotheses and addressed three research questions, revealing that biophilic design fosters sustainable behaviors. Playing a serious game with biophilic elements in a biophilic environment further strengthens sustainable behaviors compared to just being in a biophilic environment.

Our findings partially support H1. Results indicated that there is a difference between exposure to biophilic and non-biophilic environments regarding SBS, and this outcome supports the literature (Ryan and Browning, 2020; Wijesooriya and Brambilla, 2021; Zhong *et al.*, 2022). However, there is no support for sub-categories in SBS. When looking at the overall picture of sustainable behaviors, a difference is observed between the two participant groups; however, when each subcategory of SBS is examined individually, there is no specific difference in environmental identity, SCB and pro-environmental behavior. Participants tend to exhibit more sustainable behaviors when exposed to a biophilic design environment. However, when specifically analyzed, there is no significant distinction in their environmental identities, SCBs and pro-environmental behaviors.

Furthermore, the study supports H2. Combining the game with biophilic design and the biophilic physical environment has a more positive impact on participants' sustainable behavior than the environment alone. However, H3 is not supported. We could not find a significant distinct factor between real and immersive virtual environments. This result aligns with previous literature (Emamjomeh *et al.*, 2020; Yin *et al.*, 2018), suggesting no distinct factor between real and immersive virtual environments. Consequently, an immersive VR environment can be a great and valuable option for researchers with limited real-life applications.

Before we started the experiments, we assumed there would be a correlation between game scores and the sustainable behaviors of the participants. However, this assumption was not supported by the results of the analysis. Participants prioritized sustainability over high scores when selecting game items during gameplay. This may be attributed to serious games' influence as entertainment (Squire, 2003).

7. Strengths and limitations

This section evaluates the strengths and limitations of our study. Introducing a serious game to study the impact of biophilic design on sustainable behaviors adds to sustainability and behavior research. Three test conditions (real, non-immersive virtual and immersive virtual environments) enhance the study's robustness. Transparent instruments and identifying biophilic elements provide practical insights for architects and policymakers. Data collection at various stages allows comprehensive analysis, offering multidisciplinary perspectives on biophilic design and sustainable behaviors.

Our study focuses on assessing and analyzing participants' sustainable behaviors, which are fundamental to behavioral psychology. It examines how biophilic design affects behaviors, exploring psychological mechanisms and environmental impacts. Biophilic design elements were categorized into physical, visible, non-visible and noticeable elements, highlighting their influence on behavior and perceptions.

However, findings may have limited generalizability due to the specific context and controlled environment. Some participants were excluded due to motion sickness and unfamiliarity with the VR environment. The study focuses on short-term behavioral changes, not capturing long-term sustainability behaviors. Future research could address these limitations to expand understanding.

8. Conclusion

In summary, we proposed that playing a serious game designed with a biophilic approach in a biophilic environment supports sustainable behaviors. The first author developed the game, and findings showed biophilic design positively impacted participants. Gameplay in this environment influenced sustainable behavior more than other conditions. These results support using serious games as cost-effective alternatives to expensive research setups for studying environmental impacts on behavior.

Participants noted that elements of biophilic design, such as visual and non-visual connections with nature, water presence, dynamic light, sensory stimuli and mystery conditions, significantly impacted their sustainable behaviors. Future studies should examine these elements individually as Ryan *et al.* (2014) stated in their research. Literature confirms biophilic design's role in behavior, mood and cognition (Emamjomeh *et al.*, 2020; Ryan and Browning, 2020; Wijesooriya and Brambilla, 2021; Yin *et al.*, 2018; Zhong *et al.*, 2022) and our study assessed its behavioral effects on sustainability.

References

Africa, J., Heerwagen, J., Loftness, V. and Balagtas, C.R. (2019), "Biophilic Design and climate change: performance parameters for health", *Frontiers in Built Environment*, Vol. 5, doi: 10.3389/fbuil.2019.00028.

Ajzen, I. (1991), "The theory of planned behavior", *Organizational Behavior and Human Decision Processes*, Vol. 50 No. 2, pp. 179-211, doi: 10.1016/0749-5978(91)90020-T.

Aldrich, C. (2009), *The Complete Guide to Simulations and Serious Games: How the Most Valuable Content Will Be Created in the Age beyond Gutenberg to Google*, John Wiley & Sons, San Francisco.

Beck, A.T. (1976), *Cognitive Therapy and the Emotional Disorders*, International Universities Press, New York.

Bhamra, T., Lilley, D. and Tang, T. (2011), "Design for sustainable behaviour: using products to change consumer behaviour", *The Design Journal*, Vol. 14 No. 4, pp. 427-445, doi: 10.2752/175630611x13091688930453.

Bilgic, N. and Ebbini, G.W. (2023), "Balancing complexity and restoration in virtual interior environments: user perceptions of organized complexity in biophilic design", *Archnet-IJAR*, Vol. ahead-of-print No. ahead-of-print, doi: 10.1108/ARCH-07-2023-0173.

Bonnes, M. and Bonaiuto, M. (2002), "Environmental psychology: from spatial-physical Environment to sustainable development", in Bechtel, R.B. and Churchman, A. (Eds) *Handbook of Environmental Psychology*, John Wiley & Sons, New York, pp. 28-54.

Browning, W.D. and Ryan, C.O. (2020), *Nature inside. A Biophilic Design Guide*, RIBA Publishing, London.

Browning, W.D., Ryan, C.O. and Clancy, J.O. (2014), *14 Patterns of Biophilic Design*, Terrapin Bright Green, LLC, New York.

Clayton, S. (2003), "Environmental identity: a conceptual and an operational definition", in Clayton, S. and Opotow, S. (Eds), *Identity and the Natural Environment*, MIT Press, Cambridge, MA, pp. 45-65.

Clayton, S. and Kilinç, A. (2013), "Proenvironmental concern and behavior in Turkey: the role of national and environmental identity", *PsyEcology*, Vol. 4 No. 3, pp. 311-330, doi: 10.1174/217119713807749850.

Collado, S. and Corraliza, J. (2013), "Children's restorative experiences and self-reported environmental behaviors", *Environment and Behavior*, Vol. 47 No. 1, pp. 38-56, doi: 10.1177/0013916513492417.

Connolly, T., Boyle, E., MacArthur, E., Hainey, T. and Boyle, J. (2012), "A systematic literature review of empirical evidence on computer games and serious games", *Computers and Education*, Vol. 59 No. 2, pp. 661-686, doi: 10.1016/j.compedu.2012.03.004.

Corral-Verdugo, V., Tapia-Fonllem, C. and Ortiz-Valdez, A. (2014), "On the relationship between character strengths and sustainable behavior", *Environment and Behavior*, Vol. 47 No. 8, pp. 877-901, doi: 10.1177/0013916514530718.

De Vries, P.W. and Knol, E. (2011), "Serious gaming as a means to change adolescents' attitudes towards saving energy: preliminary results from the EnerCities case", *EDEN Annual Conference*, pp. 1-5.

Deci, E.L. and Ryan, R.M. (1985), *Intrinsic Motivation and Self-Determination in Human Behavior*, Plenum, New York.

Deterding, S., Dixon, D., Khaled, R. and Nacke, L. (2011), "From game design elements to gamefulness: defining gamification", *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments*, pp. 9-15, doi: 10.1145/2181037.2181040.

Emamjomeh, A., Zhu, Y. and Beck, M. (2020), "The potential of applying immersive virtual environment to biophilic building design: a pilot study", *Journal of Building Engineering*, Vol. 32, 101481, doi: 10.1016/j.jobe.2020.101481.

Ergan, S., Radwan, A., Zou, Z., Tseng, H. and Han, X. (2019), "Quantifying human experience in architectural spaces with integrated virtual reality and body sensor networks", *Journal of Computing in Civil Engineering*, Vol. 33 No. 2, 04018062, doi: 10.1061/(asce)cp.1943-5487.0000812.

Erhel, S. and Jamet, E. (2016), "The effects of goal-oriented instructions in digital game-based learning", *Interactive Learning Environments*, Vol. 24 No. 8, pp. 1744-1757, doi: 10.1080/10494820.2015.1041409.

Faul, F., Erdfelder, E., Buchner, A. and Lang, A.G. (2009), "Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses", *Behavior Research Methods*, Vol. 41 No. 4, pp. 1149-1160, doi: 10.3758/BRM.41.4.1149.

Fink, H.S. (2011), "Promoting behavioral change towards lower energy consumption in the building sector", *Innovation: The European Journal of Social Science Research*, Vol. 24 Nos 1-2, pp. 7-26, doi: 10.1080/13511610.2011.586494.

Gamberini, L., Corradi, N., Zamboni, L., Perotti, M., Cadenazzi, C., Mandressi, S., Jacucci, G., Tusa, G., Spagnolli, A., Björkskog, C., Salo, M. and Aman, P. (2001), "Saving is fun: designing a persuasive game for power conservation", *Proceeding Proceedings of the 8th International Conference on Advances in Computer Entertainment Technology, ACE'11*, pp. 1-7, doi: 10.1145/2071423.207144.

Glaser, B., Strauss, A. and Strutzel, E. (1968), "The discovery of grounded theory; strategies for qualitative research", *Nursing Research*, Vol. 17 No. 4, p. 364, doi: 10.1097/00006199-196807000-00014.

Gustafsson, A., Bång, M. and Svahn, M. (2009), "Power explorer", *Proceedings of The International Conference on Advances in Computer Entertainment Technology - ACE '09*, doi: 10.1145/1690388.1690419.

Hainey, T., Connolly, T.M., Boyle, E.A., Wilson, A. and Razak, A. (2016), "A systematic literature review of games-based learning empirical evidence in primary education", *Computers and Education*, Vol. 102, pp. 202-223, doi: 10.1016/j.compedu.2016.09.001.

Hardin, G. (1968), "The tragedy of the commons", *Science*, Vol. 162 No. 3859, pp. 1243-1248, doi: 10.1126/science.162.3859.1243.

Hartig, T., Kaiser, F. and Bowler, P. (2001), "Psychological restoration in nature as a positive motivation for ecological behavior", *Environment and Behavior*, Vol. 33 No. 4, pp. 590-607, doi: 10.1177/00139160121973142.

Ives, C., Abson, D., von Wehrden, H., Dorninger, C., Klaniecki, K. and Fischer, J. (2018), "Reconnecting with nature for sustainability", *Sustainability Science*, Vol. 13 No. 5, pp. 1389-1397, doi: 10.1007/s11625-018-0542-9.

Jin, M., Ji, L. and Peng, H. (2019), "The relationship between cognitive abilities and the decision-making process: the moderating role of self-relevance", *Frontiers in Psychology*, Vol. 10, p. 1892, doi: 10.3389/fpsyg.2019.01892.

Johnson, D., Horton, E., Mulcahy, R. and Foth, M. (2017), "Gamification and serious games within the domain of domestic energy consumption: a systematic review", *Renewable and Sustainable Energy Reviews*, Vol. 73, pp. 249-264, doi: 10.1016/j.rser.2017.01.134.

Kellert, S.R. (2008), "Dimensions, elements, and attributes of biophilic design", in *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*, Wiley, Hoboken, NJ, pp. 3-19.

Kellert, S.R. (2015), "Nature by design: the practice of biophilic design", *Human Spaces*, available at: https://blog.interface.com/nature-by-design-the-practice-of-biophilic-design/ (accessed 30 September 2020).

Kellert, S.R. and Wilson, E.O. (1993), *The Biophilia Hypothesis*, Island Press, Washington, DC.

Kellert, S.R., Heerwagen, J. and Mador, M. (2008), *Biophilic Design*, Wiley, Hoboken, NJ.

Kimura, H. and Nakajima, T. (2011), "Designing persuasive applications to motivate sustainable behavior in collectivist cultures", *PsychNology Journal*, Vol. 9 No. 1, pp. 7-28, available at: www.psychnology.org (accessed 19 April 2020).

Linehan, C., Lawson, S., Doughty, M. and Kirman, B. (2009), "Developing a serious game to evaluate and train group decision making skills", *Proceedings of the 13th International MindTrek Conference: Everyday Life in the Ubiquitous Era - MindTrek '09*, doi: 10.1145/1621841.1621861.

McGee, B., Jin, X., Park, N.-K., Ball, S. and Carr, A. (2022), "Designers' perceptions of biophilia and testing of the biophilic interior design matrix in China", *Archnet-IJAR*, Vol. 16 No. 3, pp. 517-535, doi: 10.1108/ARCH-10-2021-0279.

McKenzie-Mohr, D. (2000), "Fostering sustainable behavior through community-based social marketing", *The American Psychologist*, Vol. 55 No. 5, pp. 531-537, doi: 10.1037//0003-066x.55.5.531.

Nisbet, E.K., Zelenski, J.M. and Murphy, S.A. (2009), "The nature relatedness scale: linking individuals' connection with nature to environmental concern and behavior", *Environment and Behavior*, Vol. 41 No. 5, pp. 715-740, doi: 10.1177/0013916508318748.

Ong, C. and Araral, E. (2021), "Using a serious digital game to communicate drought risk in Singapore: an experimental study", *Environment and Behavior*, Vol. 54 No. 2, pp. 450-486, doi: 10.1177/00139165211031197.

Özgen, D.S., Afacan, Y. and Surer, E. (2020), "Save the planets: a multipurpose serious game to raise environmental awareness and to initiate change", *Proceedings of the 6th EAI International Conference on Smart Objects and Technologies for Social Good (GoodTechs '20)*, pp. 132-137, doi: 10.1145/3411170.3411253.

Parong, J., Mayer, R., Fiorella, L., MacNamara, A., Homer, B. and Plass, J. (2017), "Learning executive function skills by playing focused video games", *Contemporary Educational Psychology*, Vol. 51, pp. 141-151, doi: 10.1016/j.cedpsych.2017.07.002.

Peters, E., Dieckmann, N.F. and Weller, J. (2011), "Age differences in complex decision making", in Schaie, K.W. and Willis, S. (Eds), *Handbook of the Psychology of Aging*, Academic Press, Cambridge, MA, pp. 133-151, doi: 10.1016/b978-0-12-380882-0.00009-7.

Plass, J., Homer, B., Pawar, S. and Tam, F. (2018), "Connecting theory and design through research: cognitive skills training games", *Serious Games*, pp. 145-158, doi: 10.1007/978-3-030-02762-9_15.

Primack, B., Carroll, M., McNamara, M., Klem, M., King, B., Rich, M., Chan, C.W. and Nayak, S. (2012), "Role of video games in improving health-related outcomes", *American Journal of Preventive Medicine*, Vol. 42 No. 6, pp. 630-638, doi: 10.1016/j.amepre.2012.02.023.

Quoquab, F., Mohammad, J. and Sukari, N. (2019), "A multiple-item scale for measuring "sustainable consumption behaviour" construct: development and psychometric evaluation", *Asia Pacific Journal of Marketing and Logistics*, Vol. 31 No. 4, pp. 791-816, doi: 10.1108/apjml-02-2018-0047.

Richter, K., Winter, S. and Santosa, S. (2011), "Hierarchical representations of indoor spaces", *Environment and Planning B: Planning and Design*, Vol. 38 No. 6, pp. 1052-1070, doi: 10.1068/b37057.

Ritterfeld, U., Cody, M. and Vorderer, P. (2009), *Serious Games: Mechanisms and Effects*, Routledge, New York, p. 4.

Roungas, B., Bekius, F., Verbraeck, A. and Meijer, S. (2020), "Improving the decision-making qualities of gaming simulations", *Journal of Simulation*, Vol. 15 No. 3, pp. 177-190, doi: 10.1080/17477778.2020.1726218.

Ryan, C.O. and Browning, W.D. (2020), "Biophilic design", in Loftness, V. (Ed.), *Sustainable Built Environments. Encyclopedia of Sustainability Science and Technology Series*, Springer, New York, doi: 10.1007/978-1-0716-0684-1_1034.

Ryan, C.O., Browning, W.D., Clancy, J.O., Andrews, S.C. and Kallianpurkar, N.B. (2014), "Biophilic design patterns: emerging nature-based parameters for health and well-being in the built environment", *Archnet-IJAR*, Vol. 8 No. 2, pp. 62-76, doi: 10.26687/archnet-ijar.v8i2.436.

Salingaros, N. (2019), "The biophilic healing index predicts effects of the built environment on our wellbeing", *Journal of Biourbanism*, Vol. 8, pp. 13-14.

Salingaros, N. and Masden, K. II (2008), "Neuroscience, the natural environment, and building design", in Kellert, S., Heerwagen, J. and Mador, M. (Eds), *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*, Wiley, Hoboken, NJ.

Schuller, B., Dunwell, I., Weninger, F. and Paletta, L. (2013), "Serious gaming for behavior change: the state of play", *IEEE Pervasive Computing*, Vol. 12 No. 3, pp. 48-55, doi: 10.1109/mprv.2013.54.

Senbel, M., Ngo, V. and Blair, E. (2014), "Social mobilization of climate change: university students conserving energy through multiple pathways for peer engagement", *Journal of Environmental Psychology*, Vol. 38, pp. 84-93, doi: 10.1016/j.jenvp.2014.01.001.

Shakhshir, K. and Sheta, W. (2023), "The assessment of biophilic features in residential buildings: a case from Dubai", *Archnet-IJAR*, Vol. 18 No. 2, pp. 247-267, doi: 10.1108/ARCH-03-2023-0064.

Squire, K. (2003), "Video games in education", *International Journal of Intelligent Games and Simulation*, Vol. 2 No. 1, pp. 49-62, doi: 10.1145/950566.950583.

Stern, P.C. (1997), "Toward a working definition of consumption for environmental research and policy", in Stern, P.C., Dietz, T., Ruttan, V.R., Socolow, R.H. and Sweeney, J.L. (Eds), *Environmentally Significant Consumption: Research Directions*, National Academy Press, Washington, DC, pp. 12-35.

Stern, P.C. (2000), "New environmental theories: toward a coherent theory of environmentally significant behavior", *Journal of Social Issues*, Vol. 56 No. 3, pp. 407-424, doi: 10.1111/0022-4537.00175.

Tobler-Ammann, B.C., Surer, E., de Bruin, E.D., Rabuffetti, M., Borghese, N.A., Mainetti, R., Pirovano, M., Wittwer, L. and Knols, R.H. (2017), "Exergames encouraging exploration of hemineglected space in stroke patients with visuospatial neglect: a feasibility study", *JMIR Serious Games*, Vol. 5 No. 3, p. e17, doi: 10.2196/games.7923.

Tucker, R. and Izadpanahi, P. (2017), "Live green, think green: sustainable school architecture and children's environmental attitudes and behaviors", *Journal of Environmental Psychology*, Vol. 51, pp. 209-216, doi: 10.1016/j.jenvp.2017.04.003.

Whitburn, J., Linklater, W. and Abrahamse, W. (2019), "Meta-analysis of human connection to nature and proenvironmental behavior", *Conservation Biology*, Vol. 34 No. 1, pp. 180-193, doi: 10.1111/cobi.13381.

Wijesooriya, N. and Brambilla, A. (2021), "Bridging biophilic design and environmentally sustainable design: a critical review", *Journal of Cleaner Production*, Vol. 283, 124591, doi: 10.1016/j.jclepro.2020.124591.

Williamson, S.J. and Cummins, H.Z. (1983), *Light and Color in Nature and Art*, Wiley, Hokoben.

Yin, J., Zhu, S., MacNaughton, P., Allen, J. and Spengler, J. (2018), "Physiological and cognitive performance of exposure to biophilic indoor environment", *Building and Environment*, Vol. 132, pp. 255-262, doi: 10.1016/j.buildenv.2018.01.006.

Zhong, W., Schröder, T. and Bekkering, J. (2022), "Biophilic design in architecture and its contributions to health, well-being, and sustainability: a critical review", *Frontiers of Architectural Research*, Vol. 11 No. 1, pp. 114-141, doi: 10.1016/j.foar.2021.07.006.

Further reading

Kaiser, F.G., Ranney, M., Hartig, T. and Bowler, P.A. (1999), "Ecological behavior, environmental attitude, and feelings of responsibility for the environment", *European Psychologist*, Vol. 4 No. 2, pp. 59-74, doi: 10.1027//1016-9040.4.2.59.

Reeves, B., Cummings, J., Scarborough, J. and Yeykelis, L. (2013), "Increasing energy efficiency with entertainment media", *Environment and Behavior*, Vol. 47 No. 1, pp. 102-115, doi: 10.1177/0013916513506442.

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