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Development of a Building Evaluation Framework for Biophilic Design in Architecture

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Abstract: Biophilic design has gained prominence in architecture as a strategy to integrate natural elements into built environments, aiming to improve human comfort, well-being, and environmental sustainability. This paper critically reviews existing biophilic design frameworks, identifying gaps in their integration of health outcomes and the relationship between indoor and outdoor environments, with a primary focus on indoor environmental quality (IEQ) factors such as air quality, natural light, thermal comfort, and acoustics. The review was conducted systematically, comparing frameworks using criteria such as health benefits, human–nature connections, and user satisfaction. Key findings highlight a lack of comprehensive frameworks that explicitly link biophilic design to measurable improvements in human health, comfort, and satisfaction. To address this gap, the study proposes an enhanced biophilic design framework that bridges IEQ-focused indoor environments with urban outdoor elements, prioritizing human comfort alongside environmental sustainability. The framework also emphasizes the role of post-occupancy evaluation (POE) in assessing the real-world performance of biophilic interventions, particularly in achieving user satisfaction and ensuring long-term effectiveness. This research contributes to the advancement of biophilic design by offering actionable strategies for architects, urban planners, and policymakers to adopt biophilic principles that create resilient, healthy, and sustainable spaces. Additionally, the study emphasizes the need for empirical testing and validation of the proposed framework, including POE and user surveys, to assess its real-world impact on human well-being and satisfaction, thus setting the stage for future research.

Keywords: biophilic design; indoor environmental quality; human comfort; urban sustainability; environmental features; nature integration; well-being in architecture; sustainable urban development; human–nature connection; health and well-being; resilient environments

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1. Importance of Biophilic Design in Architecture

Biophilic design has emerged as a crucial approach in sustainable architecture, emphasizing the integration of natural systems into the built environment to enhance both human well-being and ecological sustainability [1–5]. By embedding natural elements into urban structures, biophilic design promotes spaces that are not only ecologically responsible but also psychologically fulfilling [6–8]. This approach effectively addresses urban challenges such as the heat island effect by increasing vegetation cover, shading, and evapotranspiration. These strategies reduce environmental impact while enhancing human comfort and satisfaction [9,10].

This disconnect between nature and urban settings is evident in various fields, including education, healthcare, architecture, and urban development. This underscores the need to design buildings that not only respond to sustainability challenges but also positively contribute to the surrounding environment [6,11–15].

As global climate change continues to intensify, there is a growing need to reevaluate traditional architectural practices. Newer methods must contribute positively to sustainability while prioritizing human comfort [16–18]. In this context, biophilic design

stands out compared to other sustainable architectural concepts such as Green Architecture, Climate-Responsive Architecture, Net-Zero Architecture, and Vernacular Architecture (see Table 1). These approaches each address specific aspects of sustainability; however, biophilic architecture provides a more holistic solution for fostering long-term resilience in urban environments [19–25].

Table 1. A Comparative review of architectural concepts that aim to achieve sustainability.

		Architecture with the Concepts of Sustainability				
		Green Architecture	**Climate-Responsive Architecture**	**Net-Zero Architecture**	**Vernacular Architecture**	**Biophilic Architecture**
Sustainable Components	Durability	●	⊘	●	⊘	●
	Indoor Air Quality (IAQ)	●	●	●	●	●
	Health and Well-being	⊘	⊘	⊘	●	●
	Energy and CO_2 Emissions	●	●	●	⊘	●
	Sustainable Materials	●	●	●	●	●
	Water Conservation	●	○	○	●	●
	Surface-water Run-off Pollution	○	○	○	○	●
	Waste Reduction	●	○	●	○	●
	Management	●	⊘	●	⊘	●
	Ecology	○	○	○	○	●

● Fully integrated. ⊘ Partially considered with limitations. ○ Not emphasized.

A key aspect of this reassessment involves focusing on indoor environmental quality (IEQ), which plays a vital role in optimizing occupant health, comfort, and productivity [26–29]. Given that modern humans spend approximately 90% of their time indoors [30], the quality of indoor environments—particularly in the integration of natural elements—becomes pivotal to overall well-being [8,14]. While biophilic design shows promise in addressing these concerns, more empirical studies are needed to validate its impact on health outcomes [5,8,14,31]. By addressing the needs people seek to fulfill through their built environments, architects can create spaces that are both sustainable and ecologically regenerative [3,27,32,33].

While other approaches, such as Green Architecture, emphasize energy efficiency and material sustainability, or focus on adapting buildings to climate conditions, like Climate-Responsive Architecture, biophilic architecture is distinguished by its holistic integration of sustainable components. These include durability, indoor air quality (IAQ), health and well-being, energy and CO_2 emissions, sustainable materials, water conservation, surface-water run-off pollution, waste reduction management, and ecology [3,34–38]. This broad focus on both environmental and human well-being sets biophilic architecture apart from other sustainable design concepts. For instance, Green Architecture often prioritizes measurable environmental outcomes like CO_2 emission reduction, while biophilic architecture focuses more holistically on integrating natural elements to enhance the emotional and psychological comfort of occupants [11,39–41]. Moreover, when compared to Net-Zero Architecture, which is primarily driven by energy efficiency and minimizing CO_2 emissions, biophilic architecture takes a broader approach by addressing not only energy and environmen-

tal performance but also the human experience within the space [3,42–44]. Additionally, while Vernacular Architecture is grounded in local materials and traditional techniques, biophilic architecture incorporates ecological principles to foster a strong connection with nature, addressing both the physical and emotional dimensions of the human experience in buildings [31,43–45].

The need for beneficial contact with nature is well documented, with substantial evidence linking it to improved health and well-being. However, achieving this in the built environment presents significant challenges, particularly in ensuring adequate exposure to natural light, ventilation, natural materials, and green spaces [6,8]. This disconnection has profound implications, not only for individual well-being but also for the broader goal of environmental sustainability. Therefore, biophilic design addresses these gaps by offering a more integrated approach that harmonizes indoor and outdoor experiences, particularly through elements such as natural light, ventilation, and green spaces. This integration improves the overall quality of life for building occupants [10,11,46–49].

The biophilic framework proposed in this study aims to fill the gaps left by existing frameworks, particularly by integrating both indoor and outdoor environmental factors. Existing approaches may excel in specific areas, such as energy conservation in Net-Zero Architecture or cultural responsiveness in Vernacular Architecture, but biophilic architecture incorporates a broader range of sustainable components, making it a comprehensive and flexible solution for urban development [50,51].

In conclusion, biophilic design not only addresses the pressing issues of sustainability but also enhances the quality of life for building occupants by fostering a stronger connection to nature. Its holistic approach ensures that the built environment caters to both ecological and human needs, making it an essential framework for the future of sustainable architecture [31].

2. Materials and Methods

This study employed a structured methodology to develop a comprehensive biophilic design framework, focusing on human comfort, well-being, and environmental sustainability, with a slight inclusion of outdoor elements. The methodology was divided into two key phases: (1) a systematic literature review and (2) framework development.

2.1. Systematic Literature Review

The first phase of the methodology involved a systematic review of existing biophilic design frameworks, particularly in architectural and urban planning contexts. The aim was to identify key gaps and limitations, particularly regarding human health, well-being, and environmental sustainability. This process followed a rigorous structure, detailed below.

Search Strategy

The literature search targeted peer-reviewed articles, books, and authoritative reports on biophilic design using databases such as Scopus, Web of Science, and Google Scholar. Keywords included “biophilic design”, “human comfort”, “well-being in architecture”, “sustainable urban development”, “nature integration”, and “Indoor Environmental Quality (IEQ)”. A particular focus was placed on frameworks that directly connected biophilic elements with measurable impacts on human health and environmental performance.

Inclusion/Exclusion Criteria

The following criteria guided the inclusion of studies:

- Published between 1980 and 2024.
- Direct focus on biophilic design frameworks in urban and architectural settings.
- Empirical or theoretical analysis of the impact of biophilic design on human health, well-being, or environmental outcomes.
- Studies focusing solely on natural landscapes or unrelated to built environments were excluded, ensuring the review remained relevant to architectural applications and human comfort.

Data Extraction and Synthesis

Key data were extracted on biophilic elements (e.g., natural light, vegetation, air quality), methodologies for assessing their impact, and their outcomes related to human comfort, health, and environmental performance. The comparative analysis of existing frameworks highlighted strengths, weaknesses, and areas for improvement, particularly in connecting indoor and outdoor environments and linking biophilic elements to human health benefits. Specific attention was given to frameworks that had measurable outcomes, addressing the gap identified in earlier studies.

2.2. Development of the Biophilic Design Framework

Building on the findings from the systematic literature review, this study developed an enhanced biophilic design framework, addressing gaps in the current frameworks. This phase focused on three primary areas.

Human Comfort and Well-being

The new framework prioritized measurable outcomes related to human health and comfort, including metrics such as visual comfort, air quality, stress reduction, and thermal comfort. Key biophilic design elements—such as natural ventilation, daylighting, green spaces, and water features—were integrated to enhance these outcomes in both indoor and outdoor environments.

Indoor–Outdoor Connection

A key feature of the proposed framework was the seamless integration of indoor and outdoor environments, promoting a holistic connection with nature. The framework incorporated design strategies like open spaces, balconies, rooftop gardens, and visual access to natural surroundings, aiming to foster a stronger connection between occupants and nature, thereby enhancing well-being.

Sustainability and Practical Considerations

The framework also addressed the practical challenges of biophilic design, including cost-effectiveness, scalability, and maintenance. It proposed flexible solutions that could be adapted to a range of urban settings, from residential to commercial spaces. Sustainable materials, water conservation, energy efficiency, and waste management strategies were emphasized to support the environmental sustainability component of biophilic design.

Framework Evaluation: To ensure the robustness of the proposed biophilic design framework, this study recommends empirical validation through future research, using methods such as case studies, user surveys, or experimental evaluations. These tests would assess the practical applicability of the framework across diverse built environments and its effectiveness in improving human comfort, satisfaction, and environmental performance.

3. Review of Existing Biophilic Design Frameworks

3.1. Historic Context and Evolution

The concept of biophilic design, which has been gaining increasing attention in recent architectural discourse, has deep historical roots, tracing back to humanity's inherent connection with nature. Before the industrialization and urbanization eras, human societies relied heavily on interaction with natural environments for both survival and well-being. Historically, human settlements were multi-sensory environments, where natural elements such as light, air, greenery, water, and sound played a central role in daily life [10,52,53]. These natural settings provided essential experiences that shaped emotional and psychological well-being, a connection that neuroscientific studies now confirm as a fundamental human need [54–56]. Research employing modern neuroimaging techniques has shown that contact with nature positively influences brain activity, reducing stress and promoting cognitive restoration [54–56].

The term "Biophilia", foundational to biophilic design, originates from the Greek words "philia" (love) and "bios" (life or living things). Introduced by German psychoanalyst Erich

Fromm in 1973, it describes humanity's inherent "love for life" and attraction to the natural world. This concept was popularized by American biologist Edward O. Wilson in his seminal work *Biophilia* (1984), which introduced the "Biophilia Hypothesis" [6,50]. This theory posits that humans possess an innate affinity for living systems, shaped by evolutionary processes that foster psychological and physical well-being through close interactions with nature [57–61]. Wilson's hypothesis has catalyzed further philosophical and scientific inquiries into how reconnecting with nature can enhance human health, comfort, and satisfaction.

Despite its formal recognition in the late 20th century, biophilic design is not a novel architectural concept. The integration of natural forms and elements into built environments has been prevalent throughout history, long before the term "biophilia" existed. The Art Nouveau movement of the late 19th century, for example, drew heavily on organic and natural motifs, with architects and designers like Victor Horta, Hector Guimard, Louis Comfort Tiffany, and Antonio Gaudí creating works inspired by the natural world. Their use of flowing lines, plant-like structures, and biomorphic forms served not only as decorative features but also aimed to harmonize human-built environments with nature, fostering a deeper emotional connection to the surrounding world [5,17].

Biophilic design, as it is understood today, represents a re-emergence of this long-standing human tradition of integrating natural elements into architecture. From ancient civilizations to the Art Nouveau movement and contemporary biophilic design, the use of natural forms in architecture has persisted as a means of promoting human well-being. This historical evolution underscores the critical importance of biophilic principles in modern architecture, particularly in urban contexts where nature is often absent. By integrating natural elements into urban spaces, biophilic design offers a path to enhancing human comfort, satisfaction, and health in environments increasingly detached from nature due to urbanization and technological advancements [26,62,63].

In conclusion, the historical context of biophilic design reveals a continuous effort to reconnect built environments with the natural world. As urbanization continues to reshape human living spaces, the re-integration of biophilic elements emerges not only as an aesthetic choice but as a necessary design strategy for promoting human well-being and environmental sustainability. This evolution demonstrates that biophilic design is not merely a modern trend but a fundamental design principle central to architectural practices throughout history [5,10,64].

3.2. Analysis of Biophilic Design Frameworks

Biophilic design frameworks have evolved over time, offering diverse methods to integrate natural elements into built environments with the overarching goal of enhancing human comfort, health, and well-being. This section presents a comparative analysis of seven prominent frameworks, detailing their focus areas, key dimensions, and strategies [11,65,66].

Table 2 outlines the main features of each framework, highlighting how they approach biophilic design and human–nature interaction in architectural and urban settings. The frameworks range from Kellert et al.'s focus on environmental features and natural forms to Ryan et al.'s emphasis on multi-sensory biophilic interventions. While each framework brings unique strengths, there are variations in how they address key design patterns and human well-being [11,12,32,66].

A comprehensive review of existing biophilic design frameworks reveals significant gaps, especially regarding their application to urban environments and the explicit connection between design elements and health benefits. While these frameworks emphasize biophilic principles, they often lack clarity in defining how specific urban design elements correlate with health improvements, such as enhanced air quality, stress reduction, and cognitive function [3,67].

Table 2. Comparative analysis of biophilic design frameworks.

Research	Main Focus	Dimensions/Attributes	Key Patterns/Strategies
Kellert et al. [2]	Connection between humans and nature via architecture	6 attributes: Environmental features, Natural shapes and forms, Natural patterns, Light, Place, Evolutionary perspectives	3 types of experience: direct, indirect, symbolic interaction with nature
Ryan and Browning (14 Patterns) [39]	Framework to enhance human well-being in the built environment	14 patterns: Visual connection, Non-visual stimuli, Airflow variability, etc.	Strategies for sensory experiences, restorative environments
Kellert & Calabrese (Experiences) [6]	Expands on Kellert's 2008 work by detailing direct experiences with nature	Direct (water, plants, light), Indirect (images, colors, shapes), Experience of place	Comprehensive link between environment and human interaction
Makes and Sense (Economic Benefits of Biophilic) [65]	Stress reduction, cognitive function improvement	4 major areas: Nature in space, Natural analogs, Nature of space	Patterns for sensory balance, space configuration
Brielmann et al.(Fractal Effects in Urban Design) [55]	Neuroscience of human comfort and aesthetics	Biophilic elements based on cognitive response to the environment	Principles related to fractals, complexity, and mental stimulation
Ryan and Browning, (Seven Dimensions) [18]	Framework focused on enhancing health and well-being through biophilia	7 dimensions: Visual, Non-visual, Auditory, Olfactory, Tactile, Thermal, Spatial	Multi-sensory biophilic interventions
Untaru et al. (Biophilic Interventions) [66]	Biophilic design for urban environments	Urban biophilic interventions for well-being and sustainability	Focus on green infrastructure, urban integration

For example, design elements like green courtyards, rooftop gardens, and water features are frequently recommended but without a clear articulation of their direct health benefits. This omission makes it difficult for practitioners to understand how these elements can be strategically implemented to maximize both physical and mental health outcomes [68–72]. As a result, practitioners may struggle to implement biophilic design strategies that deliver tangible health benefits, particularly in complex urban environments where these considerations are most crucial [42,73].

By explicitly linking biophilic design elements to their health benefits, as demonstrated in Table 3, this structured approach enhances the practical application of biophilic principles in urban environments. For instance, incorporating plants and natural ventilation into buildings not only improves air quality but also regulates humidity and reduces noise, contributing to overall well-being [63,74]. Similarly, green streets and pedestrian-friendly spaces foster a sense of connection with nature, improve air quality, and alleviate stress—key for urban dwellers [5,75–77].

Moreover, this structured approach addresses the need for a more user-friendly framework, where each category is clearly organized and presented. Such organization provides a comprehensive view of how biophilic design can be strategically implemented across various urban scales, ultimately benefiting the well-being of city inhabitants [8,78,79].

To fully unlock the potential of biophilic design in urban settings, future frameworks must provide clear, actionable strategies that link design elements to health outcomes. By doing so, architects and urban planners can create sustainable, resilient environments that support human well-being and ecological balance [10,80].

Table 3. Integration of biophilic design elements and health benefits into urban design components.

Urban Design Components	Biophilic Design Elements	Health Benefits
Buildings	- Green Courtyards and Roofs	- Better Air Quality - Humidity Regulation - Noise Reduction- Stress Reduction - Enhanced Cognitive Function
	- Indoor and Outdoor Plants	- Better Air Quality - Stress Reduction - Enhanced Immune System
	- Water Features/Reservoirs	- Humidity Regulation - Stress Reduction - Faster Recovery
	- Natural Daylight and Ventilation	- Better Air Quality - Stress Reduction
	- Nature Images and Paintings	- Stress Reduction - Improved Life Satisfaction
Public Spaces	- Green Areas and Pocket Parks	- Stress Reduction - Enhanced Cognitive Function—Sense of Connection
	- Ecology Parks and Native Species Yards	- Enhanced Immune System - Faster Recovery
	- Water Features/Reservoirs	- Stress Reduction - Humidity Regulation
	- Natural Sounds/Creating Artificial Nature Sounds	- Stress Reduction
Streets	- Green Streets and Road-side Parks	- Better Air Quality - Sense of Connection
	- Skinny Streets and Vegetated Swales	- Better Air Quality - Noise Reduction
Transport	- Accessibility/Pedestrian Connections	- Stress Reduction - Sense of Connection
	- Proper Road, Rail, Bicycle, and Pedestrian Networks	- Improved Life Satisfaction
Landscape	- Native and Edible Landscaping	- Enhanced Immune System - Sense of Connection
	- Thermally Treated Timber and Natural Materials	- Enhanced Cognitive Function—Improved Life Satisfaction

3.2.1. Strengths and Limitations Regarding IEQ and POE

In this section, we evaluate the strengths and limitations of these frameworks (Table 2) concerning indoor environmental quality (IEQ) and post-occupancy evaluation (POE), two critical areas for assessing building performance and human comfort.

a. Kellert et al. (Attributes) [2]

Strengths: The framework emphasizes enhancing human well-being through natural elements and evolutionary perspectives. This indirectly supports IEQ by improving the emotional and cognitive experience of users through natural light, air quality, and access to views.

Limitations: While it touches on environmental features, it does not specifically address IEQ parameters like thermal comfort, acoustics, or air quality in depth, nor does it incorporate POE for evaluating user satisfaction post-occupancy.

b. Ryan and Browning (14 Patterns) [39]

Strengths: This framework, with its 14 patterns, is more explicit about improving aspects related to IEQ, such as thermal variability, airflow, and natural ventilation, aligning directly with physical comfort factors. Some patterns also implicitly support POE through adaptability in design.

Limitations: Although it improves certain IEQ aspects, the framework doesn't offer specific guidance on post-occupancy evaluation to assess the success of these interventions over time.

c. Kellert and Calabrese (Experiences) [6]

Strengths: Their framework integrates direct and indirect experiences of nature, fostering environments that can enhance sensory experiences tied to air quality, lighting, and thermal comfort.

Limitations: The framework lacks explicit mention of IEQ standards or a structured approach to conducting POE to measure how well the space performs for users after occupancy.

d. Makes and Sense (Economic Benefits of Biophilic) [65]

Strengths: This work focuses on stress reduction and cognitive function, with some consideration of acoustic comfort and natural ventilation, tying into IEQ elements. This framework could be adapted for ongoing user evaluation via POE.

Limitations: Although it touches on comfort-related aspects of IEQ, the framework does not comprehensively cover all IEQ factors (e.g., thermal comfort and lighting quality) or provide detailed mechanisms for POE.

e. Brielmann et al. (Fractal Effects in Urban Design) [55]

Strengths: Salingaros connects biophilia to neuroscience, emphasizing mental well-being and cognitive engagement with space, which supports the psychological dimension of IEQ.

Limitations: Physical IEQ aspects like air quality and thermal conditions are not explicitly addressed. There is also no mention of post-occupancy evaluation to validate user satisfaction or comfort.

f. Ryan and Browning(Seven Dimensions) [18]

Strengths: This framework is particularly strong in addressing multi-sensory biophilic interventions, including non-visual sensory stimuli that align with IEQ. It focuses on auditory, thermal, and spatial experiences, making it relevant for enhancing indoor comfort.

Limitations: While it addresses IEQ aspects, it lacks formalized methods for evaluating the success of these interventions through POE, leaving a gap in post-occupancy assessment.

g. Untaru et al. (Biophilic Interventions) [66]

Strengths: Han's framework is more urban-focused but includes interventions such as green infrastructure and urban greenery, which can contribute to improving outdoor IEQ. It can also incorporate POE through community engagement and satisfaction metrics in urban settings.

Limitations: The framework lacks detailed strategies for evaluating indoor IEQ in buildings and does not provide structured POE techniques to track ongoing user satisfaction.

3.2.2. Identified Key Gaps

a. IEQ Gaps: Many frameworks acknowledge sensory aspects, such as natural light, air quality, and temperature regulation, but fail to address IEQ comprehensively, particularly with regard to acoustics, thermal comfort, and detailed indoor air quality standards. More integration of IEQ standards such as the ASHRAE or the WELL Building Standard® could strengthen their applicability [3,62].
b. POE Gaps: None of the frameworks explicitly includes methods or tools for post-occupancy evaluation, which is a critical gap. POE could provide valuable feedback on how biophilic interventions perform in real-world settings, guiding future improvements and ensuring sustained user comfort and satisfaction [8,31,81].
c. Recommendations for Improvement

Integrate Comprehensive IEQ Standards

Frameworks should incorporate more robust IEQ standards, ensuring a holistic approach to indoor environments that considers acoustics, thermal comfort, and air quality. The incorporation of standards from organizations such as the ASHRAE or the WELL Building Standard® would enhance the frameworks' effectiveness and applicability in various settings [3].

Establish Structured POE Mechanisms

There is a critical need for frameworks to include methods for conducting structured POE, which can help in assessing user comfort and satisfaction after occupancy. By integrating feedback mechanisms and evaluation tools, these frameworks could be continuously improved based on real-world performance and user feedback [8].

Strengths

The frameworks excel in integrating nature-based design strategies that promote well-being, stress reduction, and sensory engagement. These contribute to the overall comfort of occupants, even if IEQ and POE are not explicitly mentioned.

The use of multi-sensory design patterns is a major strength, as it encourages designers to consider more than just visual aesthetics when integrating biophilia, extending to auditory and tactile experiences.

In conclusion, while these biophilic design frameworks offer valuable approaches to enhancing human–nature interaction in architecture, they often fall short in providing comprehensive guidelines on IEQ and lack structured POE mechanisms to assess user comfort post-occupancy. Expanding these frameworks to include rigorous IEQ standards and incorporating POE would improve their application in contemporary architectural practice.

4. Biophilic Design Aspect for Human Comfort

4.1. Indoor and Outdoor Design Elements

Biophilic design presents a comprehensive approach that integrates natural elements into both indoor and outdoor environments, thereby enhancing occupant well-being and promoting sustainability. Table 4 below summarizes key aspects of indoor and outdoor biophilic design, categorizing their primary foci, key elements, benefits, challenges, and essential considerations for implementation.

Indoor biophilic design emphasizes the integration of natural elements such as plants, natural light, and water features within confined spaces, contributing to improved air quality, stress reduction, and increased productivity [3,37,81–83]. This approach is highly adaptable to various climates and locations, allowing customization based on user preferences and needs [8,53,84,85]. However, challenges such as limited space, reliance on artificial lighting, and the maintenance of indoor plants present notable obstacles [17,53,62,86–88].

Conversely, outdoor biophilic design integrates buildings and open spaces with natural surroundings. This approach factors in landscaping, weather, and biodiversity preservation, which are critical for urban planning and the conservation of green spaces [3,15,75,89–91]. While outdoor designs can be unpredictable due to natural variations, they offer significant benefits, including improved mental well-being, physical health, and community bonding [64,92–94]. These features are particularly valuable in urban settings, where access to nature may be limited [95–98].

Table 4. Aspects of indoor and outdoor biophilic design.

Aspect	Indoor Biophilic Design	Outdoor Biophilic Design
Primary Focus	Enhancing interior spaces	Integrating natural elements into outdoor environments
Key Elements	Living walls, indoor plants, natural light, water features	Green roofs, gardens, parks, natural water features, landscaping
Human Benefits	Improved air quality, stress reduction, increased productivity	Enhanced mental well-being, physical health, and community bonding
Design Integration	Incorporating nature into architecture and interior elements	Landscaping, urban planning, preservation of green spaces
Challenges	Limited space, artificial lighting, maintenance of indoor plants	Weather considerations, biodiversity preservation
Sensory Experience	Aroma, touch, visual appeal, sounds of nature	Sounds of nature, visual aesthetics, tactile experiences
Application Scales	Homes, offices, commercial spaces	Parks, public spaces, urban planning projects
Accessibility	Available in various climates and locations	Dependent on outdoor space availability, weather conditions
Cost Considerations	Initial setup costs, maintenance expenses	Initial landscaping costs, ongoing maintenance, and upkeep
Sustainability Focus	Sustainable materials, energy-efficient designs	Preservation of natural ecosystems, eco-friendly landscaping
Community Impact	Indoor green spaces within communities	Public parks, communal outdoor spaces
Wellness Connection	Mental and emotional well-being, connection to nature indoors	Physical health benefits, community well-being outdoors

4.2. Impact on Psychological and Physiological Comfort

Biophilic design, both indoors and outdoors, has a profound impact on human comfort by addressing psychological and physiological well-being. By connecting occupants with nature, this design approach transcends aesthetic appeal and fulfills the innate human need for natural interaction.

(1) Psychological Comfort: Indoor biophilic design creates calming environments that reduce stress and anxiety. The inclusion of plants, natural light, and water features indoors supports mental well-being, enhances cognitive function, and increases creativity and productivity [3,37,42,44,99,100]. Given that people spend a significant portion of their lives indoors, connecting with nature inside these spaces helps mitigate the disconnect from the natural world experienced by many urban dwellers [101–103].

Outdoor biophilic design, on the other hand, enhances psychological comfort by providing spaces for physical activity, social interaction, and relaxation in natural settings. Exposure to natural sounds, visual aesthetics, and tactile experiences outdoors significantly reduces stress, promotes mental clarity, and improves overall mood [17,26,81,104,105]. This design fosters community bonding by creating accessible natural spaces where people can gather and interact, contributing to collective well-being [5,14,18,40,106].

(2) Physiological Comfort: Biophilic design also positively influences physical health. Indoors, it improves air quality, regulates humidity, and creates more comfortable thermal environments. For example, indoor plants act as natural air purifiers, absorbing toxins and releasing oxygen, which contributes to better respiratory health and overall physical well-being [3,74,107–111]. Natural light and water features support circadian rhythms and reduce dependence on artificial lighting, promoting a healthier living or working environment [5,44,85,112].

Outdoors, biophilic design mitigates urban heat island effects through vegetation and green spaces [5,89,113,114]. Parks and gardens designed with biophilic principles provide essential spaces for exercise, relaxation, and social interaction, all of which contribute to physical well-being. Additionally, the inclusion of natural elements such as water bodies

and vegetation in urban settings helps moderate temperatures, reduce pollution, and create a healthier environment for communities [63,64,81,115].

In conclusion, biophilic design integrates nature into both indoor and outdoor spaces, significantly enhancing human comfort by addressing psychological and physiological needs. By connecting people with nature, this design approach not only improves individual well-being but also promotes a healthier, more sustainable built environment.

5. Development of a Biophilic Evaluation Framework

The newly developed framework (Table 5), Integrated Biophilic Design for Human Comfort and Sustainability, addresses critical gaps in previous biophilic design frameworks by combining indoor and outdoor design strategies with a strong focus on human comfort, sustainability, and the integration of indoor environmental quality (IEQ) and post-occupancy evaluation (POE). This framework is unique because it extends beyond traditional indoor-centric approaches by incorporating outdoor dimensions while maintaining a primary focus on indoor spaces, where people spend 90% of their time. It also prioritizes empirical data collection through POE, making it not just a design guideline but a dynamic evaluation tool that can adapt to evolving building environments and occupant needs.

Table 5. Integrated biophilic design for human comfort and sustainability.

Design Dimension	Components	Human Comfort Factors	Sustainability Factors	Integration of IEQ and POE	Performance Metrics
Direct Experiences of Nature	Natural light, plants, water features, outdoor views, fresh air	Visual comfort, air quality, emotional well-being	Energy efficiency, biodiversity, water conservation	IEQ: Focus on natural ventilation, daylight, and air quality. POE: User satisfaction with light levels, air quality, and environmental controls, extended to outdoor views and fresh air.	- Daylight availability (lux) - CO_2 concentration (ppm) - Thermal comfort (°C) - Glare index (DGI) - User satisfaction with natural features (indoor and outdoor)
Indirect Experiences of Nature	Natural materials, views of nature, nature-inspired shapes, green roofs	Cognitive engagement, psychological relaxation	Use of sustainable materials, reduced waste, integration of urban green infrastructure	IEQ: Use of low-VOC, sustainable materials indoors, green roofs for better thermal insulation. POE: Feedback on material quality, engagement with nature (views, greenery).	- VOC concentration (mg/m^3) - Visual satisfaction (survey) - Thermal resistance (R-value) - Survey: engagement with nature (views, indoor plants)
Dynamic and Diffuse Light	Daylight, circadian lighting, shading systems, skylights	Visual comfort, stress reduction, circadian support	Energy reduction, adaptability of lighting systems	IEQ: Focus on circadian lighting, dynamic daylight integration. POE: Impact of lighting on sleep cycles, mood, and productivity (indoors), with some outdoor considerations for shade.	- Circadian stimulus (CS) - Illuminance (lux) - Luminance contrast ratio - Melatonin suppression (%) - Sleep quality surveys (indoor environment focus)
Thermal and Airflow Variability	Adaptive ventilation, outdoor breezeways, natural cooling systems	Thermal comfort, cognitive performance, air quality	Energy efficiency through natural cooling, reduced HVAC demand	IEQ: Enhance thermal comfort with adaptive systems indoors, extend airflow strategies to outdoor spaces. POE: Measure satisfaction with temperature control, airflow indoors and outdoors.	- Air speed (m/s) - Operable windows usage (%) - Survey: thermal satisfaction (indoor and outdoor spaces) - Radiant temperature asymmetry (°C)
Non-visual Sensory Stimuli	Soundscapes, textured materials, natural sounds (water, wind)	Auditory comfort, tactile engagement	Reduced noise pollution, enhanced material durability	IEQ: Focus on acoustic comfort, especially with natural sound elements. POE: Evaluate responses to soundscapes and tactile materials indoors and in semi-outdoor spaces (courtyards, atriums).	- Background noise level (dBA) - Tactile response to materials (survey) - Surface texture coefficient - Sound masking and absorption (indoor and outdoor sound quality)
Spatial Variability and Prospect-Refuge	Enclosed spaces, open vistas, urban gardens, rooftop retreats	Psychological comfort, sense of safety, cognitive restoration	Flexible use of space, efficient land use	IEQ: Offer variety in spatial experiences, including enclosed and open areas, indoors and out. POE: Surveys on comfort and sense of security in enclosed vs. open spaces (indoors/outdoors).	- Occupant density (per m^2) - Privacy score (survey) - Visual connection to outdoors (window-to-wall ratio) - Sense of security and comfort (survey: indoor and outdoor)
Biophilic Urban Integration	Urban green spaces, street trees, water management systems, biodiversity	Outdoor comfort, social interaction, overall well-being	Urban biodiversity, stormwater management, pollution control	IEQ: Leverage green infrastructure for better air quality and outdoor comfort. POE: Community engagement and feedback on outdoor spaces, integration with the indoor environment.	- Pollution reduction (PM2.5/PM10) - Stormwater retention rate (mm/hr) - Urban biodiversity index (species count) - Satisfaction with outdoor spaces (surveys)

5.1. Development of Biophilic Framework and Key Strengths

(1) Holistic Integration of Indoor and Outdoor Environments

One of the most significant strengths of this framework is its inclusion of both indoor and outdoor biophilic design elements. Many existing frameworks focus primarily on indoor spaces, addressing direct and indirect experiences with nature, but often fall short in connecting these experiences with the outdoor environment. The current table bridges this gap by including outdoor strategies like urban gardens, green roofs, and outdoor views, which improve both psychological well-being and environmental performance [3].

This holistic approach is particularly innovative because it recognizes that outdoor spaces—such as rooftop gardens, green walls, or tree-lined walkways—can be as vital as indoor spaces in promoting well-being [31]. The focus on urban integration through features like biodiversity and stormwater management positions this framework as more environmentally comprehensive than many earlier models [31].

(2) Detailed Focus on Human Comfort and Well-being

Unlike earlier frameworks that are more general in their approach to human comfort [52], this table is explicitly geared towards ensuring various forms of comfort—visual, thermal, acoustic, and psychological—while also addressing cognitive and emotional needs. For instance, the Direct Experiences of Nature dimension focuses on comfort factors such as visual comfort and emotional well-being, supported by specific design interventions like natural lighting and air quality improvement [5].

What sets this table apart is the incorporation of non-visual sensory stimuli and prospect-refuge theory to create a more inclusive and adaptable environment. Non-visual sensory experiences, such as soundscapes or tactile textures, go beyond traditional frameworks that focus predominantly on the visual connection to nature [64]. These deeper sensory experiences are crucial in reducing stress and increasing occupant satisfaction, as highlighted in the table's Non-Visual Sensory Stimuli dimension.

(3) Rigorous Performance Metrics

A key differentiator of this framework is its extensive performance metrics, which are designed to be measurable and evidence-based. Existing frameworks provide qualitative strategies for implementing biophilic design, but they often lack detailed metrics for measuring success. By contrast, this table incorporates quantifiable metrics such as daylight availability (lux), CO_2 concentration (ppm), and circadian stimulus (CS). These metrics allow for the empirical evaluation of biophilic design outcomes, making it more robust and adaptable to future innovations in design and technology.

The emphasis on post-occupancy evaluation (POE) is another unique strength. POE allows for continuous feedback from occupants, enabling designers and architects to adapt the built environment to real-time needs and preferences. While POE is mentioned in other frameworks, it is often underutilized or lacks specificity [81,116]. This table, however, makes POE central by including user satisfaction surveys related to various comfort factors and performance metrics.

(4) Sustainability and IEQ Synergy

This table also successfully integrates sustainability factors with Indoor Environmental Quality (IEQ), something many older frameworks treat as separate or secondary. The Dynamic and Diffuse Light dimension, for example, focuses on the energy efficiency of lighting systems while simultaneously promoting circadian rhythm support for human health. This dual focus ensures that design choices do not just meet environmental targets but also contribute directly to occupant comfort and well-being [3,64].

Additionally, the integration of green infrastructure (such as green roofs or urban gardens) in the Biophilic Urban Integration dimension emphasizes sustainability in a way that surpasses previous models. Urban integration is also present in other frameworks, but this table adds a stronger connection between indoor and outdoor spaces by tying stormwater management, air pollution reduction, and urban biodiversity directly to human

comfort outcomes, ensuring that sustainability goals do not compromise occupant well-being [31].

5.2. Comprehensive Biophilic Design Factors for Human Comfort and Satisfaction

This section introduces a newly developed biophilic design framework aimed at enhancing human comfort and satisfaction. Building on existing frameworks, this new model integrates insights from previous analysis sections while addressing identified gaps in current biophilic design approaches. The framework's goal is to offer a more comprehensive solution that effectively targets multiple dimensions of human comfort and satisfaction within both architectural and urban spaces.

The framework was constructed by synthesizing key findings from Table 2 (Comparative analysis of biophilic design frameworks) and Table 6 (Integration of biophilic design elements and health benefits into urban design components). It categorizes biophilic elements into factors that contribute to human comfort and satisfaction while presenting both direct and indirect biophilic experiences in architecture. Additionally, the framework suggests specific biophilic elements that can be implemented to improve well-being [17,18,117].

Table 6. Comprehensive biophilic design Factors for human comfort and satisfaction.

Human Comfort and Satisfaction Factors	Direct and Indirect IntegrationExperiences in Architecture	Biophilic Elements in Architecture and Urban Design	Health and Well-Being Benefits
Visual Comfort	- Design for Natural Light - Quality and Quantity of Illumination (Natural and Artificial Light) - Access to Outdoor Views - Color and Form Harmony - Comfort Distance and Orientation	- Allowing Daylight and Balancing Artificial Light - Green Courtyards and Roofs - Vertical Green Walls and Façades - Nature Images and Paintings - Botanical Motifs - Green Streets and Pedestrian Connections	- Stress Reduction - Cognitive Enhancement - Improved Life Satisfaction
Air Quality	- Design for Natural Ventilation - Effective CO_2 Control - Integration of Plantable Resources - Ecosystem Balance - Clean Air Solutions	- Natural Airflow Distribution via Green Atriums - Indoor and Outdoor Plants - Pocket Parks and Public Landscaping - Low Impact Development (LID) - Sustainable Waste Management	- Better Air Quality - Respiratory Health Improvement - Enhanced Immune System - Humidity Control
Thermal Comfort	- Design for Natural Light and Ventilation - Selection of Thermal Mass Materials - Heat Exchange Surfaces - Water-absorbent Features - Vegetation Integration	- Allowing Natural Light and Ventilation - Thermally Treated Timber and Natural Materials like Clay, Wood, Stone - Vegetated Swales - Urban Parks and Trees - Water Features/Reservoirs	- Thermal Balance - Energy Efficiency - Reduced Heat Stress - Enhanced Comfort in Diverse Climates
Acoustics	- Sounds of Nature - Proper Sound Placement - Noise Control/ Sound Absorption - Decorative Acoustic Solutions	- Natural Soundscapes (Water, Wind, Wildlife) - Green Walls for Sound Absorption - Vegetative Buffers for Noise Reduction - Outdoor Quiet Zones - Green Streets and Roadside Parks	- Noise Reduction - Stress Relief - Acoustic Comfort - Improved Cognitive Function
Ergonomics	- Safe and Accessible Design - Human-Centered Spatial Planning - Productivity and Efficiency Focus - Aesthetic and Functional Integration	- Universal Design Principles - Human-centered Safety Measures - Gender and Age Considerations in Design - Flexible and Adaptable Spaces	- Enhanced Safety and Security - Increased Productivity - User Satisfaction - Sense of Belonging and Comfort

(1) Visual Comfort

Visual comfort emphasizes the importance of natural light, access to outdoor views, and the harmonious use of color and form [28,116]. The design incorporates elements such as green courtyards, vertical gardens, and nature-inspired aesthetics like botanical motifs,

which together create visually stimulating and relaxing environments. These strategies reduce stress, enhance cognitive functions, and increase overall comfort [44,118,119]. By ensuring that users have access to nature, either directly or indirectly, through design, spaces become more inviting and reduce mental fatigue [31,43,120,121].

(2) Air Quality

Air quality is an essential aspect of human well-being, as poor air quality is associated with respiratory issues and overall discomfort [29,67,116]. This framework emphasizes natural ventilation, CO_2 control, and the integration of plants to purify the air. Biophilic design elements such as green atriums, pocket parks, and green roofs help filter pollutants, improve air circulation, and contribute to respiratory health and the immune system's strength. Enhanced air quality fosters a healthier and more productive environment in both residential and commercial spaces [74,107,108,122].

(3) Thermal Comfort

Thermal comfort is crucial for maintaining a balanced indoor environment [123,124]. This framework enhances thermal comfort by integrating natural materials, sustainable design practices, and features such as water bodies and vegetative cover. Elements such as vegetated swales, urban parks, and green walls help regulate temperature, reduce the urban heat island effect, and provide passive cooling, making the environment more comfortable in varying climates [12,44]. These strategies not only support human comfort but also improve energy efficiency and sustainability [3,87,125].

(4) Acoustics

Acoustic comfort focuses on minimizing noise pollution and enhancing natural soundscapes. The use of natural sounds, green walls, vegetative buffers, and quiet outdoor zones promotes a tranquil environment conducive to relaxation and cognitive function [126–128]. By reducing noise levels, biophilic design helps mitigate the stress associated with urban noise pollution, thereby improving occupant well-being [129,130].

(5) Ergonomics

Ergonomics in this biophilic framework ensures that environments are safe, accessible, and conducive to productivity. By applying universal design principles and integrating human-centered safety measures such as Crime Prevention Through Environmental Design (CPTED), spaces can cater to diverse needs while enhancing safety, accessibility, and satisfaction [63,131,132]. These considerations are essential in designing spaces that accommodate users' physical and psychological comfort, thus improving both functional and emotional experiences within built environments [37,133,134].

The newly developed biophilic design framework integrates research findings with innovative strategies to effectively target human comfort and satisfaction. By addressing visual, air quality, thermal, acoustic, and ergonomic factors, the framework offers a holistic approach to enhancing the well-being of occupants. Moreover, the inclusion of urban design elements broadens its applicability across various scales, from individual buildings to entire city blocks. As a result, this framework presents a flexible, comprehensive model for biophilic design that supports human health, comfort, and sustainable urban development.

5.3. Limitations and Gaps

While this framework is a significant advancement, it does have some minimal limitations:

(1) Outdoor Focus Could Be Enhanced: Although this table introduces a more balanced approach between indoor and outdoor design elements, the outdoor components could benefit from further development, particularly in urban contexts where outdoor space is limited. Future research could explore how to optimize outdoor biophilic interventions in dense urban areas where space constraints make it difficult to implement larger green infrastructure projects [116].

(2) Empirical Validation: While the performance metrics provided are detailed and measurable, further empirical validation through long-term studies will strengthen the framework. Existing frameworks often lack this kind of empirical backing, and while this table makes a step forward, its widespread adoption will require robust, data-driven evidence that demonstrates its effectiveness in various building types and climates.

This newly developed framework is more efficient in bridging the gap between biophilic design theory and practical application. It enhances the existing frameworks from Table 7 (a comparative analysis of biophilic design frameworks) by integrating specific human comfort and sustainability factors, offering measurable performance metrics and a structured approach for implementation. However, it also presents limitations, such as potential complexity, which might challenge designers in applying these concepts effectively. Overall, the integrated design in the Integrated Biophilic Design for Human Comfort and Sustainability framework addresses the shortcomings of earlier frameworks while emphasizing the need for a comprehensive and measurable approach to biophilic design.

Table 7. Comparative analysis of previously developed and newly developed biophilic design frameworks: fostering human comfort and sustainability.

Aspect	Existing—Biophilic Design Frameworks	Newly Developed—Integrated Biophilic Design for Human Comfort and Sustainability	Comparison
Main Focus	Connection between humans and nature; enhancing well-being.	Integration of various design dimensions for comfort and sustainability.	Integrated Biophilic Design builds on the foundational principles of the existing biophilic design frameworks but provides a more comprehensive and integrated approach that directly links comfort with sustainability goals.
Dimensions/Attributes	Attributes focus on environmental features and experiences with nature.	Incorporates multiple dimensions (e.g., direct and indirect experiences) with specific components related to comfort and sustainability.	Integrated Biophilic Design's detailed components, such as dynamic lighting and thermal variability, enhance the understanding of how biophilic design can be practically applied in architectural design.
Key Patterns/Strategies	Emphasize types of experiences and strategies for sensory engagement.	Provides actionable strategies linked to specific performance metrics for each design dimension.	While the existing biophilic design frameworks outline broader strategies, Integrated Biophilic Design translates these strategies into measurable performance metrics, enhancing its practical application in design and evaluation.
Integration of IEQ and POE	Limited discussion on indoor environmental quality (IEQ) and post-occupancy evaluation (POE).	Explicitly integrates IEQ and POE for all components, focusing on user satisfaction and environmental quality.	Integrated Biophilic Design's emphasis on IEQ and POE makes it more suitable for contemporary design practices that prioritize user experience and environmental sustainability, addressing a gap in the existing biophilic design frameworks.
Performance Metrics	No performance metrics provided.	Specifies quantitative and qualitative metrics for evaluating comfort and sustainability.	Integrated Biophilic Design offers a robust framework for measuring success, which is crucial for validating biophilic design principles and their impact on human comfort and environmental performance.
Limitations	Provide a foundational understanding of biophilic design frameworks but lack specific applications.	While it includes comprehensive metrics and factors, it may become overly complex, making implementation challenging.	Integrated Biophilic Design, despite its strengths, risks overwhelming designers with too many components and metrics, which may hinder practical application in some contexts.

6. Conclusions

The comprehensive review of biophilic design frameworks highlights the significant potential of integrating natural elements into the built environment to enhance human comfort, satisfaction, and well-being. While existing frameworks, provide valuable insights into the psychological and physiological benefits of biophilic design, gaps remain in their application, particularly in urban contexts. These gaps include the need for clearer linkages between specific biophilic design elements and measurable health benefits, especially in dense urban areas where access to nature is limited.

This paper proposes an enhanced biophilic design framework that systematically categorizes and links biophilic elements to their corresponding psychological, physiological, and environmental benefits. By integrating both indoor and outdoor environmental factors, this framework offers a more holistic approach than previous models, ensuring a comprehensive application across varying scales—from individual buildings to broader urban settings. The framework emphasizes not only direct experiences of nature, such as natural light and vegetation, but also indirect experiences, such as views of nature and non-visual sensory stimuli, to foster deeper connections to nature.

The findings suggest that biophilic design contributes not only to environmental sustainability by improving energy efficiency and indoor air quality (IEQ) but also plays a crucial role in enhancing mental health, reducing stress, and fostering social well-being. This aligns with the growing recognition of biophilic design as a vital tool for creating resilient, healthy, and sustainable environments, particularly as urbanization continues to accelerate globally. The integration of outdoor urban elements, such as green roofs, biodiversity, and stormwater management, further extends the relevance of biophilic principles in achieving both human-centered and ecological design goals.

Future research should focus on refining and expanding this framework, particularly by exploring its application in diverse cultural and climatic contexts. Additionally, the development of standardized metrics for evaluating the long-term impacts of biophilic design on both human well-being and environmental health will be critical. Post-occupancy evaluation (POE) and user surveys will play a crucial role in validating the framework and ensuring its adaptability. This will facilitate the widespread adoption of biophilic design as a core component of sustainable urban development, ultimately improving the quality of life for urban inhabitants across the globe.

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Abbreviations

IAQ	Indoor Air Quality
IEQ	Indoor Environmental Quality
POE	Post-occupancy Evaluation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers

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