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Review

Biophilic Design in the Built Environment: Trends, Gaps and Future Directions

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Abstract

Biophilic design has emerged as a multidimensional response to growing concerns about health, well-being, and ecological balance in the built environment. Despite its rising prominence, research on the topic remains fragmented across building typologies, user groups, and geographic contexts. This study presents a comprehensive review of the biophilic design literature, employing a hybrid methodology combining structured content analysis and bibliometric mapping. All peer-reviewed studies indexed in the Web of Science and Scopus were manually screened for architectural relevance and systematically coded. A total of 435 studies were analysed to identify key trends, thematic patterns, and research gaps in the biophilic design discipline. This review categorises the literature by methodological strategies, building typologies, spatial scales, population groups, and specific biophilic design parameters. It also examines geographic and cultural dimensions, including climate responsiveness, heritage buildings, policy frameworks, theory development, pedagogy, and COVID-19-related research. The findings show a strong emphasis on institutional contexts, particularly workplaces, schools, and healthcare, and a reliance on perception-based methods such as surveys and experiments. In contrast, advanced tools like artificial intelligence, simulation, and VR are notably underused. Few studies engage with neuroarchitecture or neuroscience-informed approaches, despite growing recognition of how spatial design can influence cognitive and emotional responses. Experimental and biometric methods remain scarce among the few relevant contributions, revealing a missed opportunity to connect biophilic strategies with empirical evidence. Regarding biophilic parameters, greenery, daylight, and sensory experience are the most studied parameters, while psychological parameters remain underexplored. Cultural and climate-specific considerations appear in relatively few studies, and many fail to define a user group or building typology. This review highlights the need for more inclusive, context-responsive, and methodologically diverse research. By bridging macro-scale bibliometric patterns with fine-grained thematic insights, this study provides a replicable review model and valuable reference for advancing biophilic design as an evidence-based, adaptable, and human-centred approach to sustainable architecture.

Keywords: biophilic design; built environment; content analysis; environmental psychology; health and wellbeing; COVID-19

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1. Introduction

The concept of biophilia, originating from the Greek terms bios (life) and philia (affection), refers to the inherent human inclination to connect with nature and life forms [1]. Although the term was first coined by Fromm in the 1960s [2], it was popularised by Wilson in the 1980s, who proposed the biophilia hypothesis, that this human–nature connection is biologically rooted [3]. In response to the detachment from nature caused by rapid urbanisation and industrialisation, the field of biophilic design emerged to translate this evolutionary affinity into architectural and urban design strategies [4,5]. The term "biophilic design" was first introduced at a symposium titled Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. The proceedings from this event were later compiled and published as a book in 2008, where the concept of biophilic design was formally defined [5]. Unlike sustainable design, which focuses on minimising ecological impact, biophilic design aims to actively restore the human–nature relationship by integrating natural systems and elements into built environments [5–7].

A growing body of research demonstrates the psychological, physiological, and cognitive benefits of exposure to natural elements in built environments. Psychologically, exposure to nature has been shown to reduce stress, anxiety, and depression and promote emotional resilience, social cohesion and positive environmental behaviour [8–14]. Physiologically, nature contact lowers heart rate and blood pressure, enhances immune function, enhances sleep quality, reduces pain, supports recovery, and encourages physical activity [15–20]. Cognitively, natural elements help restore attention and focus [21–23], improve memory and learning [24,25] and enhance executive function, creativity [26–28], and task performance across educational and professional settings [29–32]. These benefits are increasingly relevant in today's context, where over 68% of the global population is projected to live in urban areas by 2050 [33], and individuals spend nearly 90% of their time indoors [34]. The resulting disconnection from nature is linked to widespread health issues, including Seasonal Affective Disorder [35,36], Sick Building Syndrome [37–39], and widespread vitamin D deficiency [40]. Thus, biophilic design emerges not as a stylistic trend but as a necessary intervention for health-supportive environments in contemporary urban lifestyles.

In advancing the discourse on biophilic design, a diverse body of interdisciplinary theories has established a compelling foundation for understanding how nature-integrated environments enhance human health and well-being. Central among these is Stress Recovery Theory [8,41], which emphasises the psychophysiological benefits of natural exposure through evolutionary psychology, and Attention Restoration Theory [21], which highlights nature's role in cognitive recovery via "soft fascination." These frameworks have been extended through applied models such as Supportive Design Theory [42,43], and Therapeutic Environment Theory [44], which advocate for environments that reduce stressors and enhance control, social support, and positive distractions, particularly in healthcare settings. The Evidence-Based Design approach further operationalises these ideas by promoting research-driven architectural decisions to achieve measurable outcomes [45,46]. Building on these theoretical pillars, recent developments such as Salutogenic Design [47,48], Psychosocially Supportive Design [49], and Sense-Sensitive Design [50] introduce multidimensional strategies that prioritise emotional, sensory, and social well-being. Notably, the emergence of neuroarchitecture synthesises neuroscience, architecture, and environmental psychology to explore how the built environment influences specific brain regions such as the amygdala and prefrontal cortex [51–54]. Neuroarchitectural principles align closely with biophilic objectives, offering empirical evidence that nature-inspired spaces can modulate stress responses and foster cognitive–emotional coherence [55,56].

As interest in biophilic design has expanded, several frameworks have been developed to guide its practical implementation. Kellert et al. (2008) [5] initially proposed six experiential attributes, later consolidated into three overarching categories [57]. Terrapin Bright Green [58] introduced a parallel model comprising 14 design patterns grouped into Nature in the Space, Natural Analogues, and Nature of the Space. More recently, Tekin et al. [59,60] introduced a more application-oriented framework tailored for architectural research, distinguishing between Interventional Parameters, including physical design elements, such as light, air, greenery, water, material, colour, sensory experiences, and thermal comfort, and Outcome Parameters, including psychological responses, like refuge, prospect, curiosity, circadian rhythm, sense of belonging, and feelings of relaxation or safety. This study adopts Tekin's framework to evaluate and categorise biophilic design parameters in the academic literature.

Although biophilic design began gaining popularity in the 2010s, the COVID-19 pandemic brought renewed urgency and attention to the importance of nature-accessible environments. During lockdowns, limited exposure to natural spaces amplified public concern for mental health and well-being, sparking interest in biophilic principles. As illustrated in Figure 1, online search trends for "biophilic design" have increased sharply since April 2020 and have remained elevated. This post-pandemic context has transformed biophilic design from a niche concern into a mainstream imperative. Yet, despite growing interest, implementation across building typologies and geographic contexts remains uneven, with persistent gaps in methodology, standardisation, and contextual adaptation. However, despite increasing interest, notable gaps persist in the standardisation of design parameters, methodological approaches, and contextual adaptation, highlighting the need for a systematic analysis of the current research landscape.

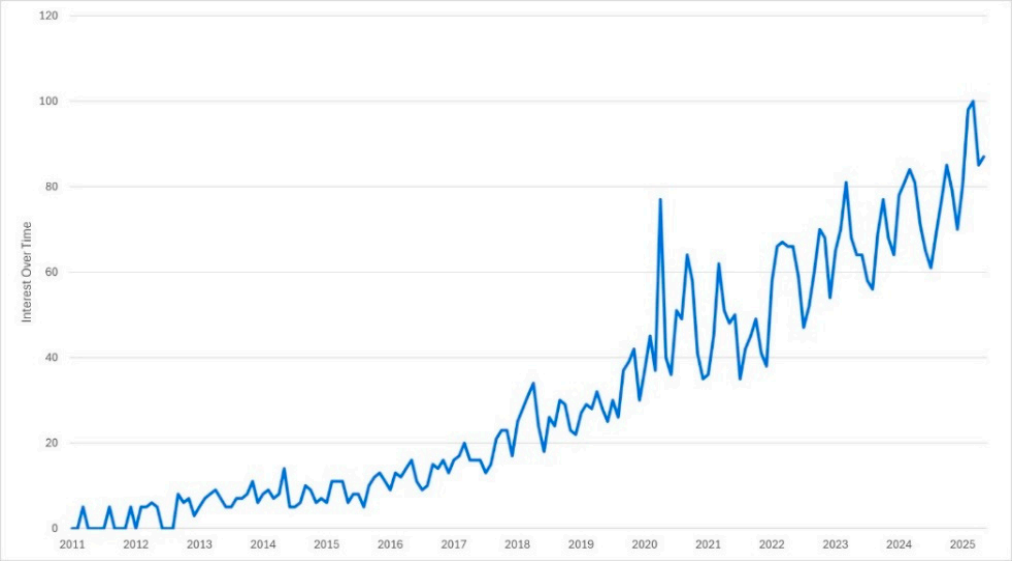

Figure 1. Google search trend for "Biophilic Design" (2011–2025).

This study seeks to map the evolution of biophilic design research within the built environment, identify prevailing trends and underexplored areas, and propose a comprehensive outlook for future research. This study examines research approaches, building typologies, user populations, geographic focus, and biophilic parameters through systematic selection of the literature, bibliometric analysis, and structured content analysis. The central question guiding this work is as follows:

What Are the Trends and Gaps in Biophilic Design Research in the Built Environment?

To address this aim, this study explores the following sub-questions:

- What are the main focus areas and directions in biophilic design research?
- Which building types, user groups, and climatic, regional and cultural contexts are represented/underrepresented?
- What methods and tools are commonly used, and where are the gaps?
- How are biophilic design parameters approached, holistically or partially, and which parameters dominate the literature?
- How is biophilic design connected to emerging fields?

This study aims to uncover new research opportunities and provide a structured reference point for scholars and practitioners by addressing this question. While several previous reviews and bibliometric analyses have examined the development of the biophilic design literature, they often focus solely on co-word analysis, keyword frequency, or publication trends. Moreover, there are quite a few studies that have systematically examined biophilic design in depth; however, they adopt a fragmented perspective, concentrating on specific aspects such as energy efficiency in biophilic architecture [61] or emotional responses within biophilic urbanism [62], without addressing the field holistically. In response, the present review adopts a hybrid methodology that combines bibliometric mapping with structured manual content analysis and introduces a dual-coding framework to assess both design parameters and contextual dimensions. This approach enables more nuanced, cross-comparative insights into methodologies, user groups, climate responsiveness, and disciplinary integration, including emerging intersections such as neuroarchitecture. Accordingly, this study offers a broader and more detailed synthesis to guide future research and practice. Ultimately, we aspire to deliver a holistic and evidence-based understanding of biophilic design, advancing its application as a human-centred, adaptive, and health-promoting strategy in architecture and the built environment.

2. Methodology

This study adopts a hybrid and novel methodological framework that combines bibliometric mapping techniques with structured content analysis. Unlike conventional bibliometric reviews, this study does not analyse all records retrieved through keyword searches. Instead, a manual abstract screening stage is included to ensure that publications contribute meaningfully to the topic within the context of architecture and interior design. This step improves the accuracy of co-occurrence and citation analyses by filtering out irrelevant or misleading records.

The final set of screened publications is used in two complementary ways. In addition to bibliometric analysis, the same dataset is evaluated through structured content analysis using a custom Excel-based coding system. This dual approach enables macro-level mapping of the research field and micro-level examination of thematic, methodological, and contextual characteristics. These include variables, such as research type, spatial focus, target users, and biophilic design parameters.

This two-track method provides layered and detailed insights that cannot be achieved through either quantitative or qualitative analysis alone. This study aims to understand both the structural development of biophilic design as a research area and the practical knowledge it produces across different settings and needs. The whole process is illustrated in the methodological workflow (Figure 2).

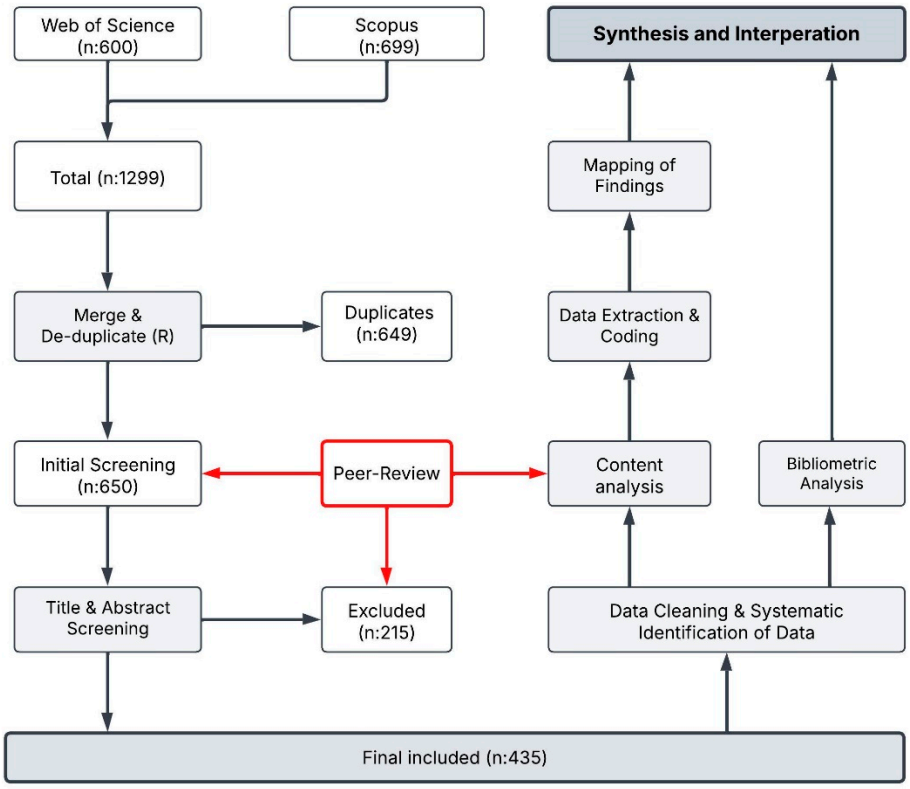

Figure 2. Methodological workflow of this study.

2.1. Data Search and Collection

The preparation phase of this study began with a systematic literature search conducted on 22 March 2025 in the Web of Science Core Collection and Scopus databases. The Boolean string ("Biophilic" OR "biophilia") AND ("design" OR "architecture" OR "building" OR "interior design") was applied to Title, Abstract, and Keyword fields in both Web of Science and Scopus to capture relevant publications from an interdisciplinary perspective. No time filter was applied, as biophilic design remains a relatively new and evolving field. All available records in the Web of Science Core Collection (SSCI, SCIE, A&HCI, ESCI) up to March 2025 were included without restricting sub-datasets in order to comprehensively trace the development of research on this topic. It is important to note that Web of Science subscriptions are customised at the institutional level, which may result in slight variations in database access and document availability across universities [63]. To minimise this bias and ensure broader dataset integrity, searches were conducted through access points at four different university libraries located in two countries. This approach ensures that the analysis captures the full temporal trajectory of the field since its emergence.

The initial search retrieved 1155 records. The raw records were then imported into R (4.4.3), a software platform for performing statistical analysis and creating data visualisations [64], and processed via the Bibliometrix (4.1) package, a tool for comprehensive science mapping analysis [65]. This step involved cleaning 505 duplicate entries and merging metadata across the two databases to produce a unified dataset. The result was a pool of 650 unique publications. This dataset was then subjected to manual abstract screening in Rayyan.ai, a tool that facilitates systematic reviews by accelerating the initial screening of titles and abstracts through a semi-automated workflow [66]. Each abstract was reviewed independently by at least two researchers using a double-blinded process by considering the inclusion and exclusion criteria (Table 1). Records were labelled as include, exclude, or maybe.

Table 1. Inclusion and exclusion criteria.

Criterion Type	Applied Criteria
Inclusion	Peer-reviewed research articles or review papers
	Published in English
	Explicitly or contextually focused on biophilic design.
	Conducted within the built environment context (architecture, interior design, buildings, public or institutional spaces)
Exclusion	Use of the term "biophilic" in purely metaphorical, figurative, or branding contexts
	Studies focused solely on biological, ecological, or environmental science perspectives unrelated to the built environment.
	Document types such as conference proceedings, book chapters, editorials, abstracts, or dataset-only publications
	Keyword-matching documents whose actual content does not address biophilic design

- 421 studies were directly included after agreement between reviewers.
- 198 were excluded based on shared judgment.
- 31 studies with conflict or uncertainty (21 maybes, 10 disagreements) were resolved through panel review of four reviewers, and 17 were excluded.
- This process resulted in 435 publications being retained for analysis (see Supplementary Materials Table S1 for the complete list of publications).

Exclusion decisions in this study were guided by several thematic and contextual criteria to ensure the relevance and consistency of the dataset (Table 1). Studies were excluded if they focused on unrelated fields, such as wildlife, agriculture, soil science, or general sustainability planning. Papers that used the term "biophilic" only metaphorically or incidentally, such as in the conclusion without substantive discussion, were also excluded. Additionally, works set in non-architectural contexts, including logo, product, or furniture design, were not considered. Studies that approached biophilic design purely from a psychological perspective or misused the concept were also omitted. Further exclusions were made for documents lacking essential bibliographic information, unsupported publication types like editorials, book chapters, and conference proceedings, and for duplicate records found across databases.

2.2. Analysis of Bibliometric Data

Unlike traditional bibliometric approaches that analyse all records retrieved by keyword search, this study applies bibliometric analysis to a carefully screened dataset of 435 publications. These records were selected through manual abstract screening to ensure that each publication directly contributes to the research topic. The analysis produced more consistent and meaningful insights by excluding conceptually irrelevant or misleading records.

The analysis was conducted using the Bibliometrix (4.1), R (4.4.3) package, and its graphical interface, Biblioshiny. Bibliometrix (4.1), was selected over alternative tools such as VOSviewer (1.6.20) because it allows for advanced statistical customisation within the R environment and seamless integration with manually coded variables from the structured content analysis. This flexibility enabled a more coherent synthesis between bibliometric mapping and qualitative thematic analysis. This research aimed to explore the intellectual structure, conceptual development, and publication networks in the field of biophilic design through a set of core indicators. The outputs are grouped under the following key themes:

- Trends in scientific production and country contributions.
- Author productivity and institutional collaboration networks.
- Journal impact and source relevance.
- Keyword co-occurrence and thematic mapping.
- International co-authorship and collaboration patterns.

These analyses provide a comprehensive view of the evolution of the biophilic design literature, showing how it has developed quantitatively, what conceptual areas it centres around, and where scholarly interaction is geographically concentrated. Moreover, the results informed the structured content analysis phase by highlighting dominant themes and gaps in the field.

2.3. Structured Content Analysis

In parallel with the bibliometric analysis, a structured content analysis was conducted on 435 screened publications. Rather than focusing solely on publication volume or citation impact, this analysis aimed to examine the studies' structural, methodological, and thematic dimensions in greater detail.

The process was guided by a predefined data extraction protocol, developed at the outset of the research and operationalised through a customised Excel spreadsheet. Each publication was independently coded by four researchers across multiple categories. A coding agreement was reached in approximately 93% of cases. Discrepancies were resolved through consensus discussion between the coders. If consensus could not be reached, the case was reviewed by a panel of four authors to determine the appropriate classification. While formal inter-coder reliability statistics such as Cohen's Kappa were not calculated, the multi-step resolution process ensured consistency and methodological rigour.

Results were cross-checked for consistency, and in cases of disagreement, records were jointly reviewed to reach consensus, ensuring methodological rigour and reliability.

The coding categories were initially informed by established frameworks in the biophilic design literature, including Kellert et al. (2008) [5] and Tekin et al. (2023) [59]. These were then refined inductively during a pilot coding phase involving a representative subset of publications, allowing us to ensure relevance, clarity, and coverage across diverse research contexts. The coding framework covered the following key dimensions (the data extraction tool, along with content subgroups, categories, and detailed descriptions, is provided in Supplementary Materials Table S2):

- Type of Approach: whether biophilic design was the primary research focus or used as a supporting concept.
- Field and Scale: the spatial context of the study (e.g., architecture, interior, landscape).
- Methodological Strategy and Method Type: qualitative, quantitative, mixed-method, or theoretical.
- Research Theme: categorised into domains, such as architectural practice, education, standards, theory, and policy.
- Climate Reference and Country/Region.
- Cultural References: religious, traditional, or heritage-oriented dimensions.
- Target Population: students, patients, workers, children, etc.
- Building Typology: schools, hospitals, offices, residential buildings, etc.
- Biophilic Design Parameters.
- Overall Approach: holistic or partial.
- Specific Parameters: light, vegetation, water, natural materials, sound, scent, thermal comfort, and other sensory/environmental aspects.

This structured and multi-dimensional analysis allowed the identification of user orientations, spatial coverage, typological patterns, and the extent to which specific biophilic principles were applied. It complemented the bibliometric results by offering qualitative depth, revealing underexplored areas, and highlighting methodological and contextual gaps within the literature.

The dual-method approach combining bibliometric analysis with structured content analysis not only provided complementary insights but also enabled a synthesis process based on multi-layered data integration. Through this, conceptual trends identified in the literature were examined alongside empirical distributions such as geography, building type, and user focus. This cross-structured analysis enabled the exploration of not just quantitative growth but also the qualitative distribution of research across typologies, populations, and climatic zones. It provided a foundation for identifying thematic and methodological gaps and guiding future research directions outlined in this study's subsequent sections.

3. Analysis of Bibliometric Insights of Biophilic Design Research

This section presents a bibliometric analysis of 435 peer-reviewed studies on biophilic design. The analysis aims to uncover publication trends, leading contributors, collaborative networks, influential journals, and thematic developments in the field. This review highlights the evolution, current landscape, and emerging directions of biophilic design research by examining structural patterns and keyword co-occurrences. The bibliometric analysis of the field offers a comprehensive understanding of the field's growth, disciplinary reach, and future potential.

3.1. Annual Scientific Production

The annual scientific production data (Figure 3) demonstrate a significant upward trend in biophilic design research, particularly after 2019. While the number of publications remained low and relatively stable from 2006 to 2015, interest in the field began to grow gradually between 2016 and 2019. A notable acceleration occurred from 2020 onwards, with the number of studies increasing sharply each year and peaking at 111 in 2024. This surge likely reflects a growing awareness of health, well-being, and sustainability in architectural discourse, especially following the COVID-19 pandemic. Additionally, it should be noted that the increase in publication volume may also be partially attributed to the expansion of database coverage in Web of Science and Scopus over time [67].

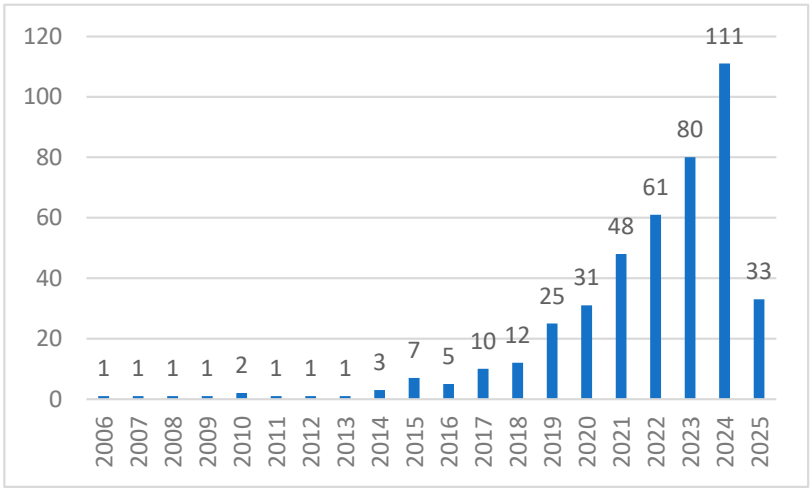

Figure 3. Annual scientific production on biophilic design (2006–2025).

Although the number drops to 33 in 2025, this is due to the data collected in March and does not indicate a decline. Overall, the trend suggests that biophilic design has transitioned from a niche interest to a prominent area of academic inquiry, with strong potential for further development and diversification.

3.2. Geographic and Institutional Contributions

The co-authorship network by country (Figure 4) highlights the USA as the most central and interconnected actor in biophilic design research. Positioned prominently at the centre of the network, the USA demonstrates strong collaborative ties with several countries, including Canada and Italy. A distinct Southeast Asia–Pacific cluster, comprising Australia, China, and Singapore, demonstrates particularly dense regional collaboration, while a European-centric cluster, centred on Germany, Switzerland, and the Netherlands and extending to France, Spain, and Denmark, underscores the continent's collective contribution. Notably, Oman and Iran have also integrated into these networks, collaborating with multiple European nations and signalling an expanding global reach for biophilic design research. Meanwhile, several countries such as Turkey and Estonia appear more isolated, suggesting limited integration into the broader collaborative network. The United Kingdom plays a unique mediating role, serving as a bridge between Indonesia, Jordan, and more central research nodes, thus linking Western and non-Western scholarly communities. The diversity of nodes and interconnections suggests a growing global interest in biophilic design; however, the unevenness of collaboration points to the need for more inclusive international research efforts, especially involving underrepresented regions. Applying deeper network analyses considering geopolitical, linguistic, and funding disparities may help explain why certain regions remain disconnected. Comparative collaboration studies across income groups could support strategies for integrating underrepresented regions into the global research community. Strengthening international partnerships may lead to a more holistic and culturally nuanced field development.

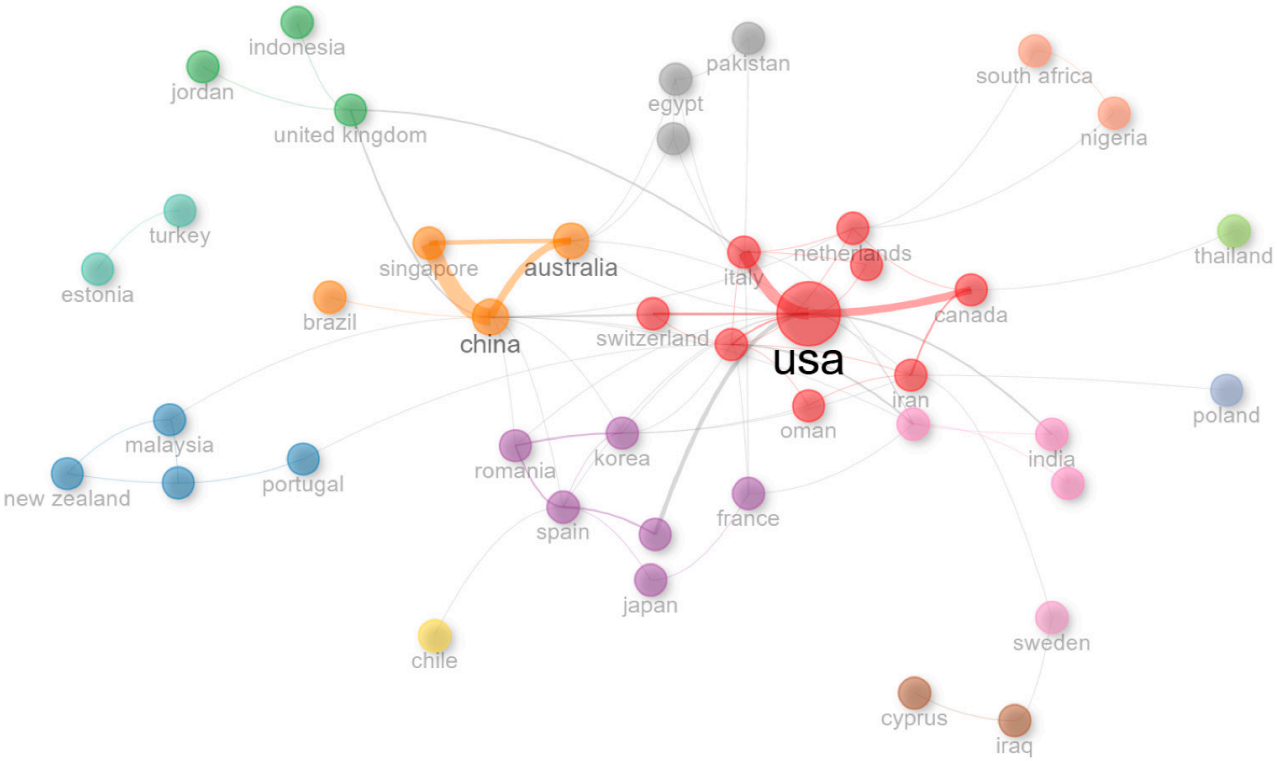

Figure 4. Co-authorship network by country in the biophilic design literature.

Figure 5 illustrates publication trends from 2006 to 2025 for the five leading countries in biophilic design research: the USA, Australia, Canada, China, and the United Kingdom. The publication trends by country reveal that the USA has maintained a dominant position in biophilic design research, especially from 2015 onward, with a sharp and continuous rise in output. Australia and Canada follow, showing steady growth from around 2017 and experiencing accelerated increases after 2020. China exhibits a notably rapid climb beginning in 2021, quickly closing the gap with other leading countries and indicating emerging leadership in the field. The United Kingdom, while contributing consistently, demonstrates a comparatively modest growth trajectory.

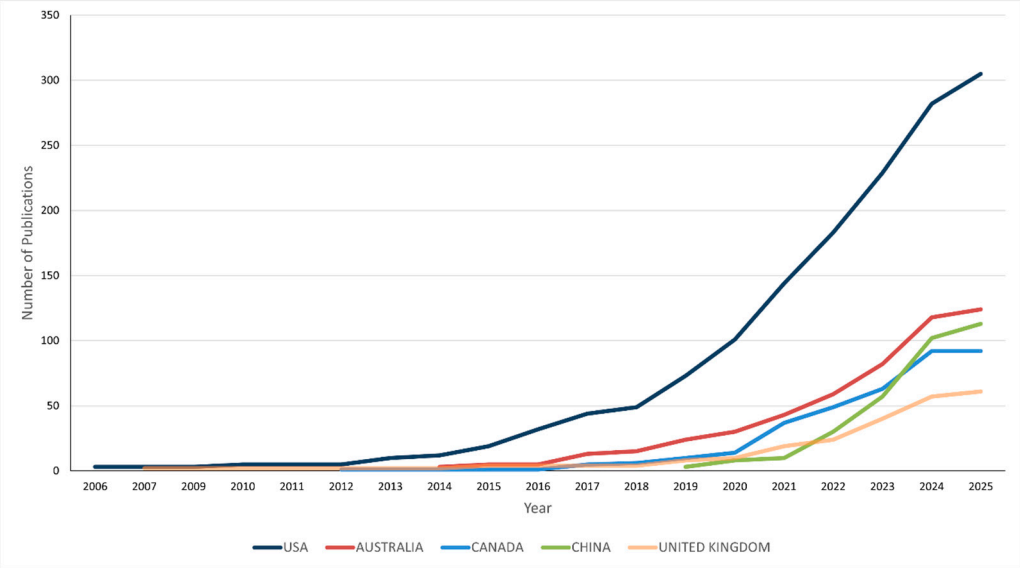

Figure 5. Publication trends by country in biophilic design research (2006–2025).

These trends suggest growing global engagement in biophilic design, particularly post-2020, likely influenced by the heightened focus on health, well-being, and sustainable environments [68]. However, the disparities in publication volume highlight the need for broader geographical representation. Encouraging contributions from underrepresented countries could help diversify perspectives and foster more context-sensitive approaches in biophilic design research.

The most productive 10 institutions in biophilic design research demonstrate notable geographical diversity (Figure 6). Université Laval and the University of Toronto from Canada, along with Deakin University, the University of Sydney, and the University of Melbourne from Australia, are among the leading contributors. Universiti Teknologi MARA (Malaysia) and Beihang University (China) are also prominently featured in Asia. In addition, the list includes Texas Tech University from the USA, Bilkent University from Turkey, and the University of Liverpool from the United Kingdom. This range highlights the global engagement and multidisciplinary interest in biophilic design across both Western and non-Western academic institutions.

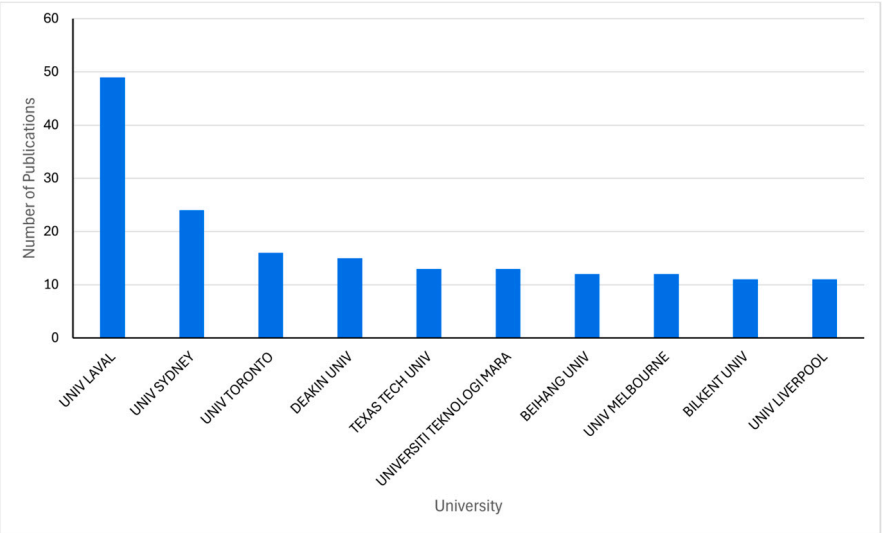

Figure 6. Most productive institutions in biophilic design research.

3.3. Authorship and Collaboration

The author collaboration network in biophilic design research reveals a relatively fragmented structure, with multiple small clusters and limited large-scale collaboration (Figure 7). Demers C is the most prominent and central contributor, forming a dense cluster with collaborators such as Jean-François J, Lalonde J, and Parsaee M, indicating a strong, cohesive research group [69–73]. Other visible clusters, such as those connected by red links, reflect regional or thematic partnerships but remain comparatively isolated.

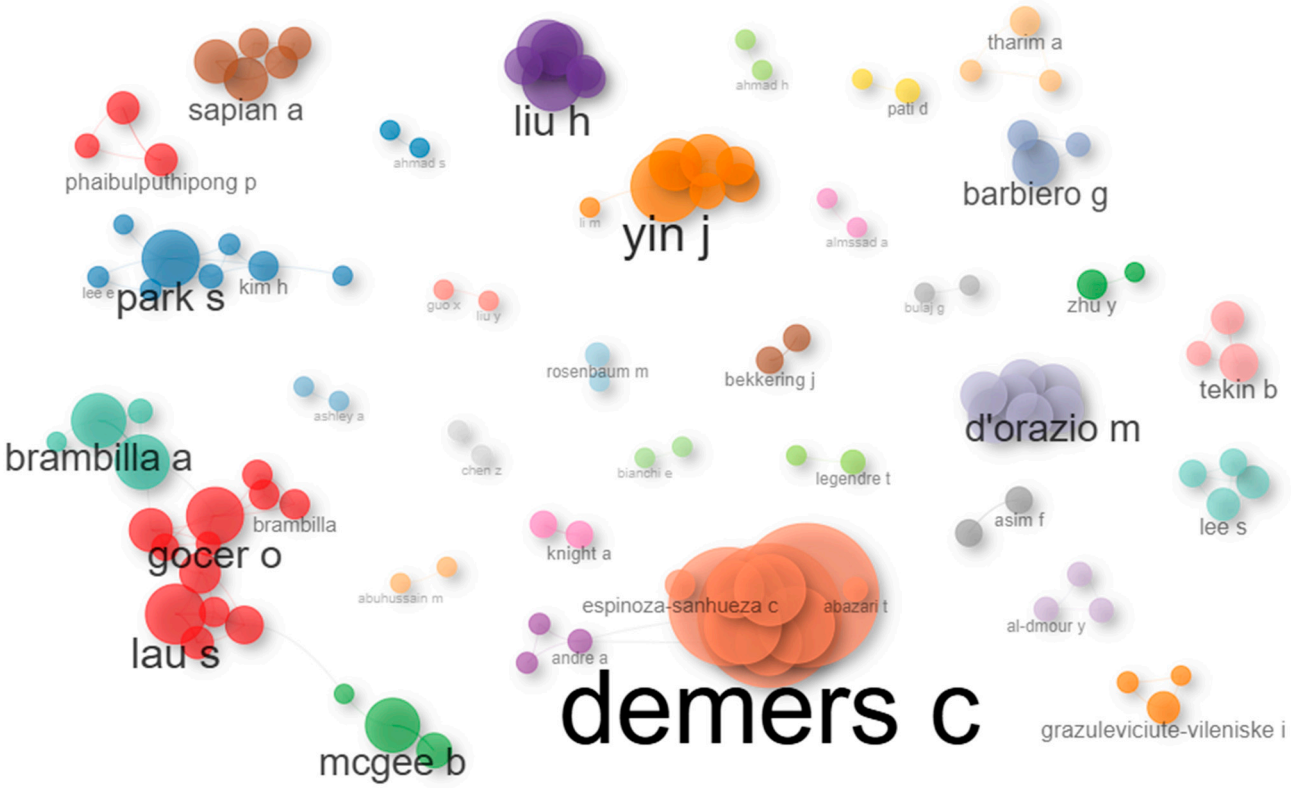

Figure 7. Author collaboration network in biophilic design research.

Most groups are composed of just two–four co-authors, suggesting focused collaborations rather than broad research networks. The dispersed nature of the map indicates that, although biophilic design is a growing field, cross-institutional and international author collaboration is still limited. This highlights an opportunity for increased integration and networking to strengthen the global biophilic design research community.

3.4. Influential Journals

Figure 8 highlights the impact of publication volume and citations on key journals in biophilic design research. While *Buildings* leads in the number of publications (32 articles), *Building and Environment* stands out with the highest citation count (811), indicating strong influence and academic reach despite slightly fewer articles (29). Other journals, such as *Sustainability*, *Frontiers in Psychology*, and *HERD* contribute significantly both in volume and citations, reflecting the field's interdisciplinary nature across environmental design, health, and psychology. This distribution suggests that impactful biophilic research is not only growing but also diversifying across multiple domains [74].

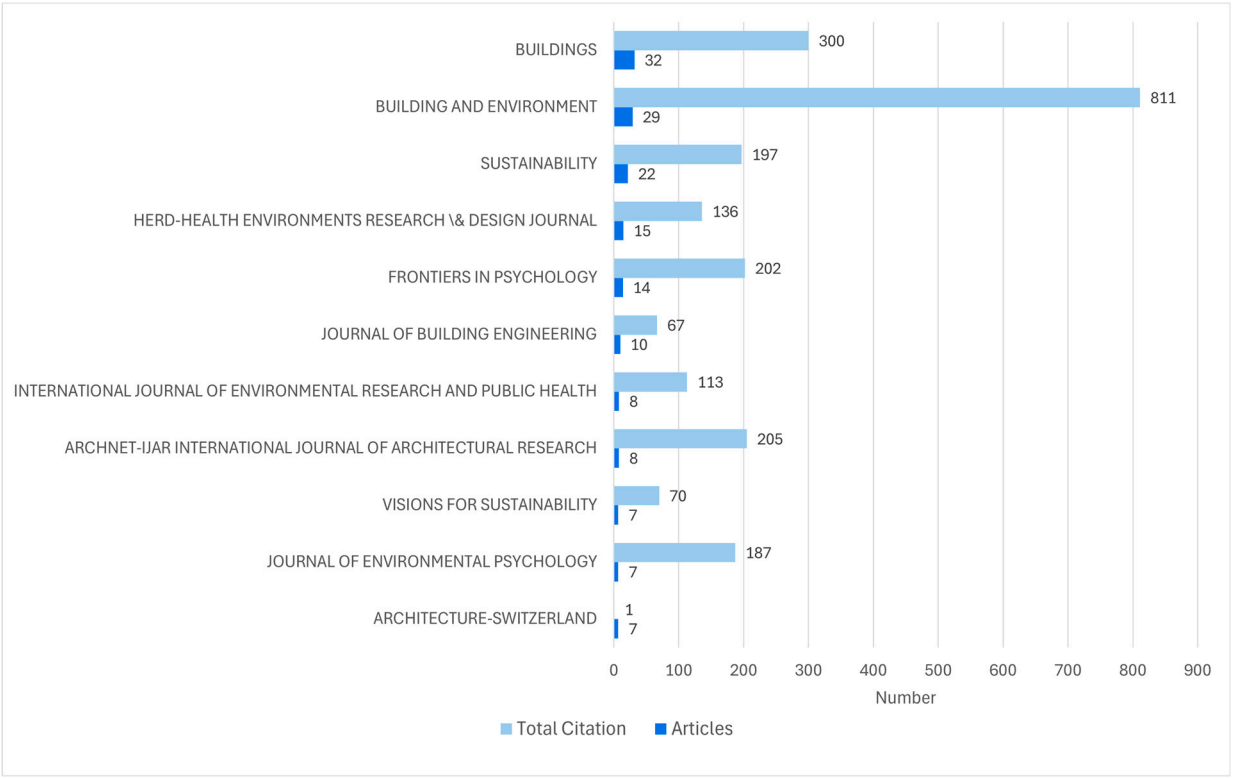

Figure 8. Publication output and citation impact of leading journals in biophilic design research.

3.5. Keyword Trends and Thematic Directions

The keyword word cloud (Figure 9) shows that frequently used terms include "biophilic," "design," "environment," and "nature," reflecting a strong emphasis on human–nature connections in design. Health-related terms such as "well-being," "stress," and "impact" are also prominent, underlining the growing interest in measurable outcomes. Spatial and architectural concerns are reflected in words like "building" and "space," while emerging themes such as "virtual reality" and "sustainability" suggest interdisciplinary convergence.

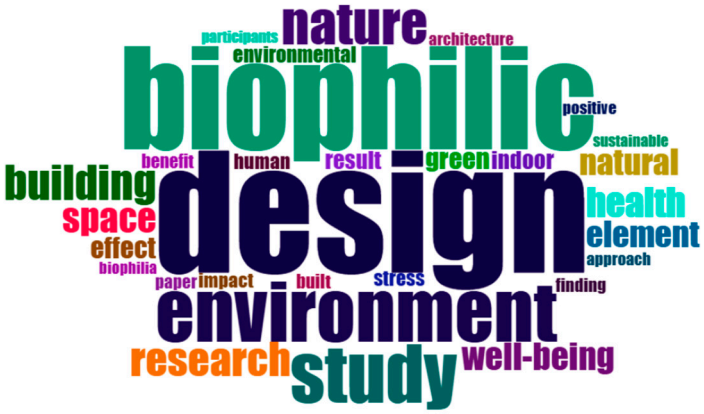

Figure 9. Word cloud of keywords.

Figure 10 illustrates the dominance of "biophilic design" and its conceptual core "biophilia" and "well-being" but also reveals a significant thematic diversification within the field. Beyond these central terms, the presence of keywords such as "virtual reality", "sustainability", "stress", and "nature" signals a strong interdisciplinary convergence, particularly towards digital, environmental, and psychological research frontiers.

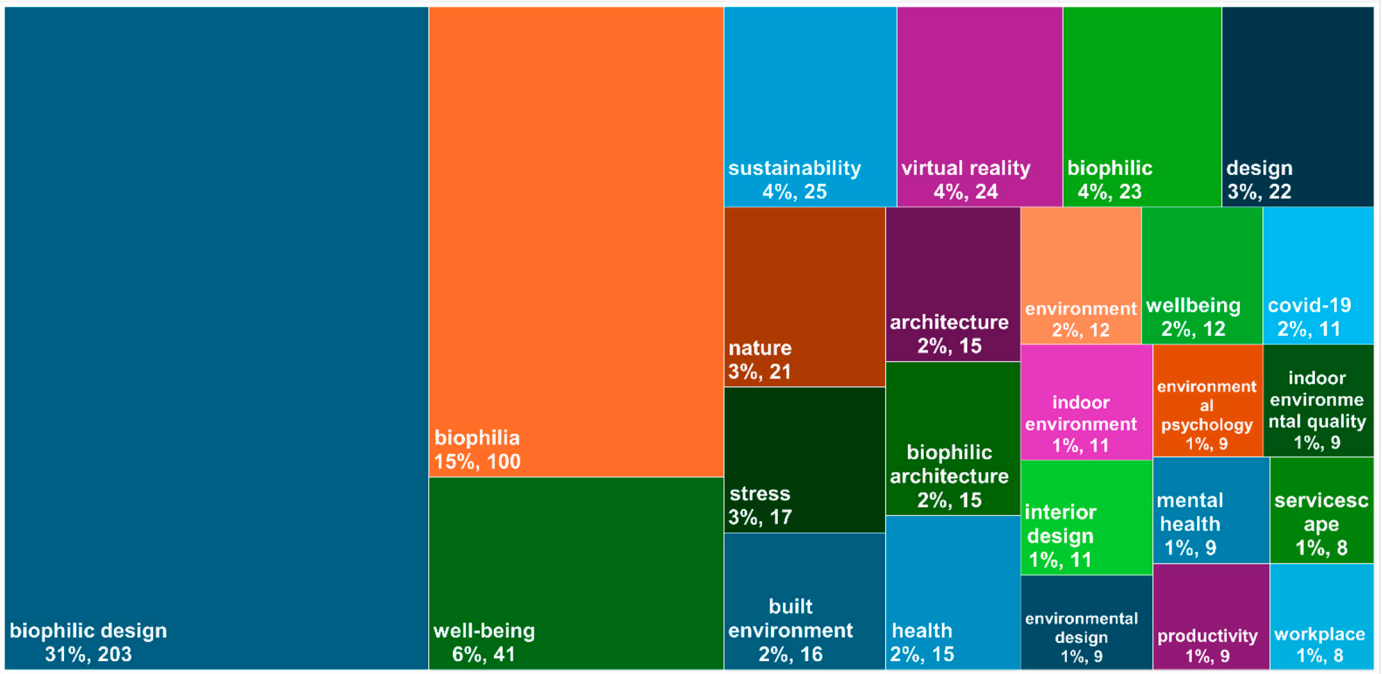

Figure 10. Keyword distribution in the biophilic design literature (treemap visualisation).

Notably, the frequency of "virtual reality" (4%) suggests a rapidly emerging intersection between biophilic design and technology, marking a notable shift towards exploring immersive and digital experiences. The concurrent prominence of health-related terms (e.g., "mental health," "attention restoration," "heart rate," etc.) highlights a parallel trend towards integrating physiological and psychological well-being within biophilic discourse.

The broad array of secondary terms, including "architecture", "indoor environment", "environmental psychology", and "workplace", demonstrates that biophilic design research now spans not only multiple scales and typologies but also draws from diverse disciplinary perspectives, cementing its position as a truly interdisciplinary field. A longitudinal analysis of keyword usage over time, especially terms like "mental health," "VR," and

"sustainability", could reveal how research priorities have evolved, particularly after pivotal events such as the COVID-19 pandemic.

The keyword co-occurrence network in biophilic design research (Figure 11) reveals two distinct thematic clusters, each highlighting different conceptual priorities within the field. At the centre of the network, "biophilic design" serves as the dominant and most frequently connected term, indicating its role as the field's conceptual anchor.

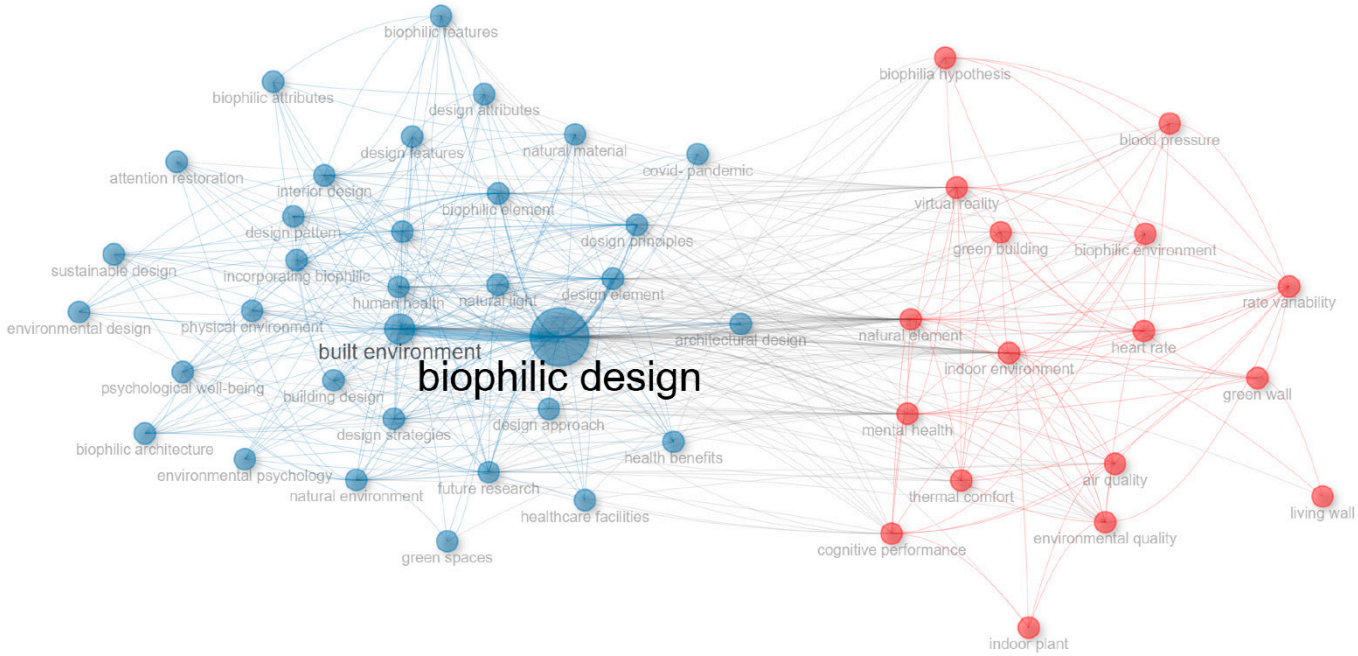

Figure 11. Keyword co-occurrence network of biophilic design research based on abstract data.

On the red cluster, the keywords are primarily associated with health-related outcomes and environmental psychology. Terms, such as heart rate, mental health, cognitive performance, and indoor plant, suggest a strong focus on the physiological and psychological impacts of biophilic environments. This cluster emphasises evidence-based studies that explore how natural elements influence human health and indoor environmental quality. Conversely, the blue cluster represents a design- and application-oriented perspective. Keywords, like design features, architectural design, green spaces, design strategies, and environmental design, reflect the growing interest in the practical integration of biophilic principles in architecture and urban planning. The presence of terms like future research, COVID-19 pandemic, and psychological well-being also suggests a forward-looking trend that ties biophilic design to recent global challenges and evolving design paradigms.

Overall, the network demonstrates a dual focus in the literature: one grounded in human-centred health impacts [59,75–77] and another in the application of design theory and practice [5,57,58,60]. This division points to the multidisciplinary nature of biophilic design and highlights future opportunities for bridging these domains through more integrated, cross-sectoral research.

The bibliometric analysis reveals that biophilic design has rapidly evolved into a globally recognised and multidisciplinary research area, particularly in the last five years. While countries like the USA, Australia, and China lead in productivity, collaborative networks remain fragmented, and participation from underrepresented regions is limited. The field is supported by various institutions and journals, reflecting theoretical depth and applied relevance. Keyword analysis strongly focuses on human well-being, environmental psychology, and spatial design, while emerging trends point toward digital integration and policy-related discourse. The field would benefit from more inclusive international

collaboration, broader typological exploration, and stronger empirical grounding in underexplored areas such as cultural context, regulation, and education [78]. The following section presents a detailed content analysis of the included studies to build on these findings, examining their methodological approaches, building typologies, user populations, and thematic focus areas.

4. Structured Content Analysis of Biophilic Design Research

This section presents the key findings from a structured content analysis of 435 peer-reviewed studies on biophilic design. The aim is to move beyond bibliometric patterns and provide a detailed understanding of how biophilic design is applied, interpreted, and examined in various research contexts. The analysis explores methodological strategies, spatial typologies, population focus, climate and cultural responsiveness, as well as the specific biophilic design parameters addressed. It distinguishes between studies that take a general or holistic view and those that focus on specific parameters in depth. Through this lens, this review reveals dominant practices, underexplored themes, and gaps that suggest opportunities for more inclusive, contextual, and empirically grounded future research.

Of the 435 studies reviewed, 368 directly addressed biophilic design as a central theoretical framework, while 67 indirectly engaged with the idea, often as a secondary theme or within broader discussions of sustainability and well-being. Regarding spatial focus, 296 studies examined biophilic design at the building scale, and 205 focused specifically on interior environments. Although studies exclusively focused on biophilic urbanism were excluded, 30 included urban-scale considerations alongside building-scale analysis, and 19 engaged substantially with landscape design.

4.1. Methodological Strategies

An analysis of methodological strategies, based primarily on abstract content, revealed that 87 studies used qualitative approaches, 144 employed quantitative methods, and 81 adopted mixed-methods strategies. Notably, 120 studies did not specify their methodological approach in the abstract, highlighting a lack of reporting consistency.

The methods employed across the 435 studies show a clear dominance of empirical and user-centred approaches (Figure 12). Surveys were the most common method, used in over 150 studies, reflecting a strong emphasis on capturing user perceptions and experiences. Experimental methods appeared in 98 studies, underscoring interest in testing and validating the impact of biophilic design. Literature reviews (85 studies) and systematic reviews (37 studies) suggest ongoing efforts to consolidate theoretical knowledge.

Qualitative methods such as case studies, conceptual frameworks, and observation are widely used and consistent with the design-oriented and interdisciplinary nature of biophilic research. A variety of less common but noteworthy methods, including VR/AR technologies, environmental measurement, simulation, and biochemical analysis, indicates a growing trend towards integrating technological and scientific tools. However, these remain underrepresented. Niche and advanced methods, such as eye tracking, AI and machine learning, economic valuation, and participatory design, appear in only a few studies, highlighting an opportunity for methodological expansion. Within this context, research explicitly linking biophilic design to neuroarchitecture and neuroscience is particularly limited. From the systematic search, only 11 studies were identified as relevant to neuroarchitecture, with just 5 directly applied to the built environment. These included two experimental studies [79,80], one systematic review [81], one bibliometric analysis [82], and one on-site case study [83], suggesting that while interdisciplinary interest is emerging, it has yet to translate into a robust body of applied research. This scarcity highlights a critical opportunity for future work to more deeply explore how neuroscientific methods, such as

biometric sensing, brain imaging, or cognitive performance metrics, can be harnessed to evaluate and inform the design of nature-integrated, neuro-responsive environments.

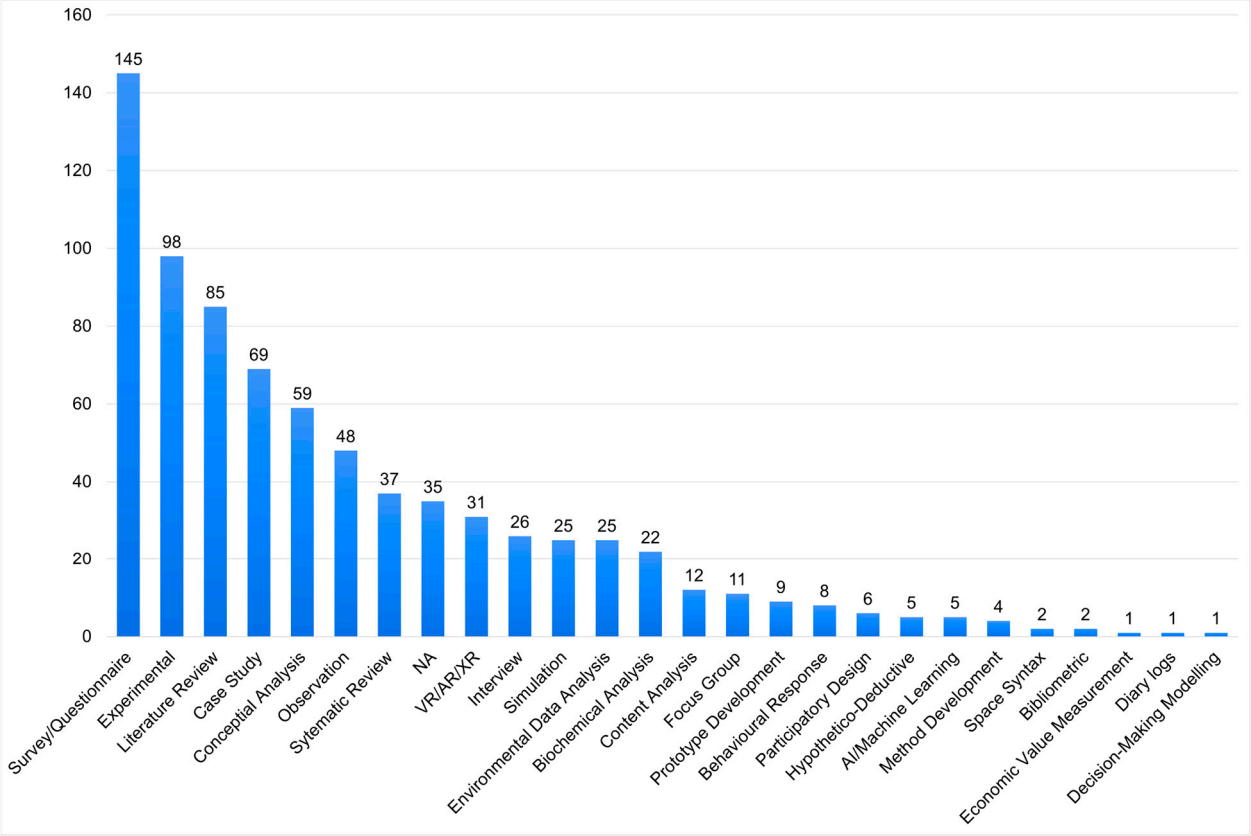

Figure 12. Number of studies by methods.

Although artificial intelligence represents a significant trend in contemporary research across disciplines [84], it is striking that only five studies in the field of biophilic design have employed AI-related methods. This limited adoption suggests a significant gap and untapped potential for leveraging AI technologies, such as machine learning, image recognition, and predictive modelling, to deepen our understanding of biophilic patterns, user responses, and design optimisation [85,86].

Overall, while the field demonstrates considerable methodological diversity, it remains heavily weighted towards subjective and perception-based tools. Future research may benefit from a broader integration of mixed methods, particularly those that combine qualitative insights with objective, data-driven approaches, to more comprehensively assess the impact of biophilic design. For instance, combining spatial performance data with physiological measures (e.g., heart rate variability, cortisol) and user interviews could help triangulate results and overcome the bias of perception-based tools [87].

4.2. Biophilic Design Research in Practice

While theoretical frameworks and conceptual discourse have played a central role in shaping biophilic design research, an increasing body of work now focuses on how biophilic principles are implemented, tested, and evaluated in real-world settings. This research explores the applied dimensions of the field by examining studies that address practical aspects, such as geographic and cultural contexts, climate-responsive strategies, building typologies, population groups, and methodological approaches. By analysing these factors, this study highlights how biophilic design is being operationalised across di-

verse environments, identifies patterns in practical applications, and uncovers critical gaps in implementation that need to be addressed to strengthen the field's impact and relevance.

4.2.1. Geographic Focus of Case Studies

Of the 435 studies, 124 specified the country in which their case studies were conducted (Figure 13). China leads with 14 cases, reflecting its recent growth in biophilic design research revealed in Figure 5. Canada and Malaysia each contributed 13 case studies, with Malaysia notable for its high rate of applied work despite a lower overall publication volume. By contrast, countries with high publication counts, such as the USA (10), Australia (11), and the UK (9), had relatively fewer case-based studies, suggesting a greater focus on theoretical or generalised frameworks.

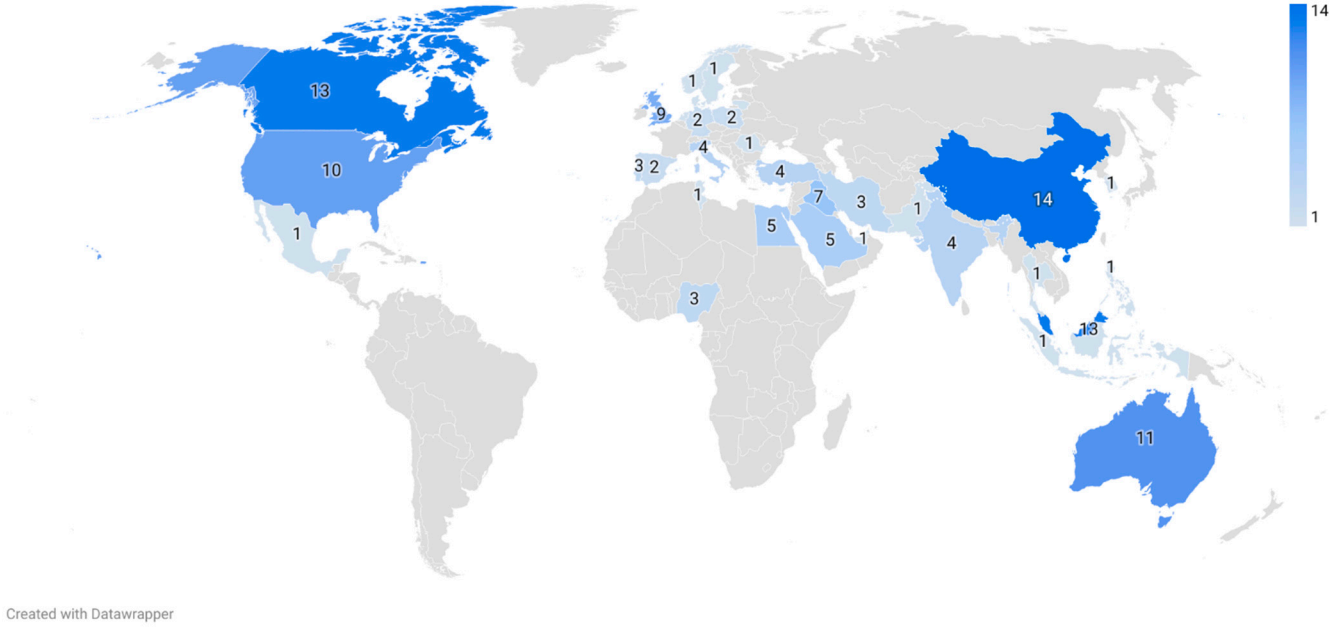

Figure 13. Geographic focus of case studies.

Meanwhile, countries such as Iraq, Egypt, and Saudi Arabia contribute more case studies than expected given their total output based on the bibliometric analysis, indicating a strong emphasis on context-specific application. This contrast highlights a gap between theoretical development and practical implementation, underscoring the need for more applied research in leading publishing countries and greater visibility for case-driven work in emerging regions.

While the literature remains heavily concentrated in the Global North, China is increasingly emerging as a dominant case context, with growing contributions also observed in Southeast Asia and the Middle East. However, regions such as South America and Africa remain significantly underexplored, underscoring the need for geographically grounded theories and culturally adaptive biophilic frameworks that reflect a broader range of environmental and socio-cultural contexts.

4.2.2. Cultural Considerations

Biophilic design should be approached through a contextual lens that considers climate, population, culture, and building typology [6,60]. These factors critically shape how natural elements are integrated and experienced within the built environment. However, cultural considerations remain significantly underrepresented in the literature; only 15 studies explicitly reference cultural context in their biophilic design approach [88,89]. This study further examined how the reviewed publications address climate, typology, and

population, revealing that while these dimensions are occasionally acknowledged, they are often treated superficially or inconsistently. A more holistic and context-sensitive framework is needed to guide future research and implementation of biophilic design principles across diverse environmental and socio-cultural settings.

4.2.3. Climate-Specific Analysis

Climate is a critical contextual factor in the implementation of biophilic design, influencing the selection, performance, and appropriateness of natural elements within built environments [70,90–92]. Despite this, an overwhelming majority of the studies reviewed, 379 out of 435, made no reference to climate considerations, indicating a significant gap in the literature (Table 2). Only eight studies included general references to climate without specifying particular climatic zones. Among the remaining studies that did mention climate explicitly, references were scattered and limited: cold and polar climates were the most frequently noted (14 studies), followed by arid and hot climates (8 studies) [93,94], with very few studies addressing other zones, such as subtropical, tropical [95], hot humid [96], or Mediterranean conditions. This uneven and minimal representation suggests that climate-specific strategies in biophilic design remain largely underexplored. Given that the effectiveness of biophilic interventions is closely tied to environmental conditions, this lack of climatic sensitivity highlights a crucial area for future research, especially in developing design frameworks that are responsive to regional climates, cultural norms, population needs, and building typologies. Integrating climatic context more deliberately could significantly enhance the applicability and sustainability of biophilic design across diverse settings [91].

Table 2. Number of studies by climate references.

Climatic Conditions	Count
NA	379
Climate Reference (General)	8
Arid and Hot	8
Cold and Polar	14
Continental	1
Hot humid climate	1
Mild/Moderate	5
Subtropical	2
Tropic	1
Warm Mediterranean	1

Analysis of climate-specific studies across building typologies reveals a significant gap in climate-responsive biophilic design research (Table 3). Education settings are the most frequently addressed, particularly in cold and polar climates (six studies) [97], with additional coverage across arid [90], Mediterranean, tropical, and humid zones. Other typologies, such as residential, healthcare, and workplaces, are mentioned less frequently and typically within one or two climate categories [98]. Many relevant typologies, such as retail, prisons, transport hubs, and religious spaces, have no climate-specific studies at all. A notable number of studies with no fixed typology still reference climate, suggesting conceptual rather than applied engagement. Overall, the data highlight an urgent need to integrate climate considerations more systematically across diverse building types in biophilic design research.

Table 3. Co-occurrence of climate and typology analysis.

	General Climate Ref.	Continental	Arid and Hot	Warm Mediterranean	Tropic	Subtropical	Mild Moderate	Hot Humid	Cold and Polar
Healthcare Facilities	0	0	1	0	0	1	0	0	0
Educational Buildings	3	0	2	1	1	0	1	1	6
Workplaces	0	0	0	0	0	0	2	0	0
Residential Buildings	1	0	1	0	0	0	1	0	1
Hospitality Facilities	0	0	1	0	0	0	0	0	0
Open Spaces	0	0	1	0	0	0	0	0	0
Museum/Pavilion	0	0	1	0	0	0	0	0	0
NA	2	1	2	0	0	1	0	0	7

Table 4 reveals that even in studies acknowledging climate, biophilic design is often treated broadly rather than through a detailed exploration of specific parameters. Partial consideration of the parameters mentioned is slightly more frequent than general or holistic mentions in several climate zones, notably in cold and polar areas (five studies), while partial approaches are more prevalent in cold and polar climates (eight studies) [69,70,72,73,97,99]. This suggests a fragmented application of biophilic concepts under extreme conditions.

Table 4. Co-occurrence of climate and biophilic design parameter analysis.

	General Climate Ref.	Continental	Arid and Hot	Warm Mediterranean	Tropic	Sub-Tropical	Mild Moderate	Hot Humid	Cold and Polar
General/Holistic	5	0	4	0	0	1	2	1	5
Partial	3	1	4	1	0	1	3	0	8
Light/Daylight	2	0	2	0	1	0	2	0	10
Natural View	2	0	1	0	0	1	2	0	5
Outdoor Green	2	0	3	1	0	0	0	0	1
Indoor/Balcony Green	3	0	1	0	1	1	1	0	0
Green Roof/Wall	0	1	1	0	0	1	1	0	0
Artificial	0	0	0	0	0	0	0	0	1
Biomimicry-Form	1	0	1	0	0	0	0	0	0
Material	1	0	1	0	0	0	0	0	0
Water	0	0	1	1	0	0	0	0	0
Colour	0	0	0	0	0	0	0	0	2
Fresh Air-Ventilation	1	0	2	0	1	1	1	0	3
Sensory Experiences	3	0	4	0	0	0	1	0	2
Thermal Comfort	0	0	1	0	0	0	1	0	4
Animal	0	0	0	0	0	0	0	0	0
Prospect	1	0	0	0	0	0	1	0	2
Refuge	1	0	0	0	0	0	1	0	1
Curiosity	2	0	0	0	0	0	1	0	1

Among specific parameters, daylight is the most consistently addressed, particularly in cold and polar climates (10 studies), indicating a strong interest in mitigating light scarcity [70,72,100]. Natural views, sensory experiences, and indoor greenery are also considered across several climates, though to a lesser extent [99]. In contrast, parameters such as green spaces, animal presence, and artificial/natural artistic references are virtually absent, suggesting limited thematic diversity in climate-sensitive biophilic research.

Furthermore, thermal comfort and ventilation are mainly addressed in hot, humid and cold climates, reflecting climate-adaptive performance concerns [73,89,90,94,97,99]. Emotional or psychological parameters like prospect, refuge, and curiosity are sparsely mentioned and appear mostly in cold climates.

These findings indicate that, although some attention is given to climatic variability, most biophilic parameters remain underexplored across different climate zones. The prevalence of general references and selective parameter use underscores the need for more comprehensive and climate-responsive approaches in future biophilic design research.

4.2.4. Population Focus

The analysis of user groups across the reviewed biophilic design studies reveals distinct patterns in population focus (Table 5). The most frequently studied population is staff, workers, and employees, with 104 studies addressing this group. This emphasis aligns with the broader interest in workplace design and its impact on productivity, well-being, and environmental quality [20,101,102]. Students are the second most commonly examined group, appearing in 68 studies, reflecting significant attention to educational settings and the role of nature in supporting learning environments [103,104]. Patients follow with 44 studies, recognising the therapeutic potential of biophilic design in healthcare contexts [20,101]. Guests, consumers, visitors (33 studies) and residents (24 studies) are also represented, though to a lesser extent, indicating moderate engagement with hospitality and residential environments. Meanwhile, age-based populations show a diverse but uneven focus: children are examined in 24 studies, older adults in 10, and only 1 study explicitly focuses on adults, suggesting a potential oversight of the general adult population as a distinct category. However, it is essential to note that many studies categorised under the student population likely refer to children and adolescents, even though they were not classified explicitly within the age-based categories.

Table 5. Number of studies by population groups.

Workers		104
Students		68
Patients		44
Guests		33
Residents		24
Age Based	Children	24
	Adult	1
	Elderly	10
Built Environment Professional		17
General		51
Space Explorers		2
NA		105

Research involving design professionals, including architects, planners, and other experts, appears in 17 studies, suggesting some interest in the role of designers as both users and shapers of biophilic environments [59]. Notably, astronauts and space explorers are featured in two studies, pointing to niche but innovative exploration of biophilic principles in extreme and closed environments [105]. Finally, 51 studies address the general population without defining a specific user group, and 105 studies do not specify any population. The high number of unspecified or broadly defined user groups reflects a significant limitation in current biophilic design research, which may reduce the applicability and impact of findings across distinct user needs. Tailoring biophilic strategies to specific populations, such as children, neurodiverse users, or older adults, could enhance both user satisfaction and functional performance (reference). Design approaches, therefore, might include sensory zoning, refuge spaces, or gentle natural acoustics to better suit these groups.

These observations highlight a disproportionate focus on specific institutional populations, such as workers, students, and patients, while many others remain understudied. Broadening the scope of research to include more diverse and underrepresented groups,

particularly within residential, community-based, and age-specific contexts, will be critical for fostering more inclusive and user-responsive biophilic design practices.

The co-occurrence table of methods and populations strongly relies on surveys and experimental designs (Table 6), particularly in studies involving staff/workers (46 and 26 studies, respectively), students, and patients. These methods dominate institutional contexts like workplaces, schools, and healthcare. VR and simulation are increasingly used with students and patients, reflecting growing interest in immersive tools. Qualitative methods such as interviews, focus groups, and site observations are more common with children, residents, and older adults, indicating a need for nuanced engagement. Review-based methods, especially literature and systematic reviews, are often applied in studies without defined user groups, highlighting a general rather than user-specific focus. Less common methods like participatory design, biochemical analysis, and AI tools remain underutilised and mostly appear in niche or professional contexts. The high number of studies with unspecified populations suggests a gap in user-centred research [106], underscoring the need for more targeted and inclusive methodological approaches in biophilic design.

Table 6. Co-occurrence of population and method analysis.

	Workers	Students	Patients	Guests	Residents	Child	Adult	Elderly	Built Env. Experts	General	Space Exp.	NA
Survey/ Questionnaire	46	25	12	16	11	8	1	3	6	19	0	16
Experimental	26	20	9	10	5	5	0	1	1	13	0	13
VR/AR/XR	5	9	1	1	3	0	0	1	1	7	0	3
Simulation	7	2	2	0	4	0	0	0	0	4	0	8
Interview	7	3	3	2	5	4	0	1	4	1	0	3
Focus Group	4	5	0	1	0	1	0	0	1	0	0	2
Observation	15	7	6	3	3	4	0	0	1	3	0	13
AI/Machine Learning	0	1	1	0	0	0	0	0	1	0	0	2
Bibliometric	0	0	0	0	0	0	0	0	1	0	0	1
Systematic Review	13	2	6	2	2	2	0	2	0	5	0	11
Content Analysis	1	0	1	1	1	1	0	0	0	4	0	3
Literature Review	17	11	12	2	3	4	0	4	5	12	0	24
Prototype Development	0	2	0	1	0	0	0	0	1	1	0	3
Participatory Design	3	4	0	0	0	1	0	1	0	0	0	0
Case Study	16	15	7	8	4	8	0	0	2	9	0	15
Conceptual Analysis	12	5	7	4	2	3	0	0	6	11	2	17
Environmental Data Anal.	9	6	0	2	2	1	0	0	0	4	0	4
Economic Value	1	1	0	0	0	0	0	0	0	0	0	0
Hypothetico-Deductive	2	0	1	2	1	0	0	0	0	0	0	0
Biochemical	7	3	3	0	3	0	0	1	0	6	0	0
Space Syntax	1	1	0	0	0	0	0	0	0	0	0	1
Behavioural Response	2	3	0	0	0	2	0	0	0	1	0	1
Decision-making Modelling	0	0	0	1	0	0	0	0	0	0	0	0
Diary Logs	0	0	0	0	0	0	0	1	0	0	0	0
Method Development	1	1	0	0	1	0	0	1	1	0	0	0
NA	4	4	2	2	3	1	0	0	1	3	0	17

4.2.5. Building Typology

The analysis of building typologies reveals a strong concentration in a few key sectors (Figure 14). Workplace environments (81 studies), educational settings (69 studies), and healthcare facilities (60 studies) dominate the research landscape, indicating a primary focus on institutional contexts where the impact of biophilic design on productivity [107], learning [108,109], and healing [59,60,110] is well documented. Housing/accommodation (40 studies) and hospitality venues (22 studies) follow, suggesting

growing interest [98,111,112] in residential and semi-public applications of biophilic principles. In contrast, typologies such as shopping/retail (15), experimental/laboratory settings (16), and construction-related studies (11) appear less frequently, highlighting a more limited exploration of commercial, technical, and transitional spaces.

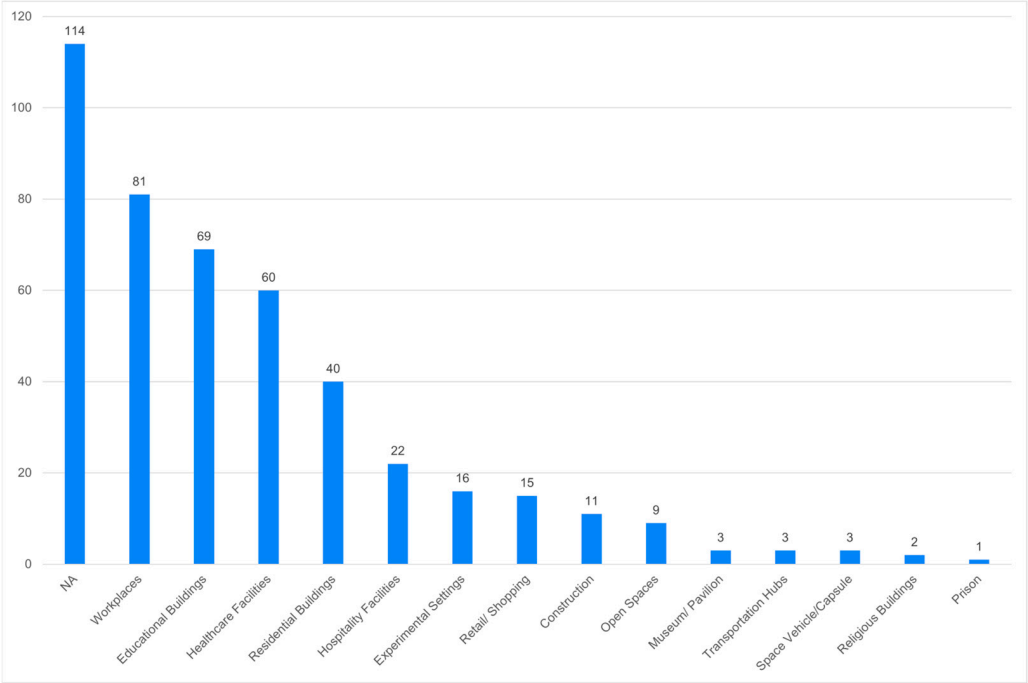

Figure 14. Number of studies by typology.

Notably, specific typologies are minimally represented or nearly absent, including prisons (one study), urban/open spaces (nine), religious/sanctuary spaces (two), and transportation hubs (three), despite their potential relevance to public health and well-being. Additionally, space-related environments (three studies) represent an emerging yet highly specialised domain. More marginal contexts, like prisons [113], public transport [114], space capsules [105], and sanctuaries [115], show minimal coverage, highlighting biophilic design's nascent or neglected application in these critical and often high-stress environments. Developing a design framework for these neglected building types could strengthen the field's inclusivity. For example, integrating views of nature and calming sensory experiences in transit spaces or correctional environments might address stress, anxiety, and behavioural regulation [113]. A significant portion of studies (114) are classified as NA, indicating that they either did not specify a building typology or addressed biophilic design in a conceptual or cross-typological context.

Table 7 reveals a dominant reliance on survey questionnaires, particularly in the workplace (37 studies), education (26), and healthcare (19) settings. This indicates a preference for quantitative, perception-based methods in institutional environments where user feedback on productivity [107], learning [108,109], or well-being [58] is central. Similarly, experimental designs are heavily used in workplaces (30) and educational spaces (14), suggesting these typologies are primary testing grounds for controlled, hypothesis-driven research in biophilic design [103,116].

Table 7. Co-occurrence of typology and method analysis.

	Healthcare Facilities	Educational Buildings	Workplaces	Residential Buildings	Hospitality Facilities	Retail/ Shopping	Prisons	Open Spaces	Constructions	Experimental Settings	Religious Buildings	Museum/ Pavilion	Transportation Hubs	Space Vehicle/ Capsule	NA
Survey/ Questionnaire	19	26	37	16	10	8	0	5	4	9	0	2	2	0	21
Experimental	11	14	30	7	8	4	0	3	3	13	0	0	1	0	12
VR/AR/XR	3	4	10	4	0	0	0	0	0	6	0	1	0	0	5
Simulation	4	1	5	6	0	0	0	0	0	1	0	0	1	0	9
Interview	4	6	4	5	2	1	0	0	0	0	0	0	0	0	5
Focus Group	0	3	2	1	0	1	0	0	2	0	0	0	0	0	4
Observation	8	14	9	4	2	1	0	3	0	0	2	1	0	0	8
AI/Machine Learning	1	1	0	0	0	0	0	0	1	1	0	0	0	0	2
Bibliometric	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Systematic Review	7	4	8	4	1	1	0	0	1	0	0	0	0	0	13
Content Analysis	1	1	0	1	1	0	0	1	1	0	1	0	0	0	4
Literature Review	13	10	12	7	2	0	0	2	6	0	0	0	0	1	34
Prototype Development	0	1	0	1	1	0	0	0	1	0	0	0	0	0	4
Participatory Design	1	2	1	0	0	0	0	0	0	0	0	0	0	0	2
Case Study	11	16	11	9	4	4	0	3	2	1	0	1	2	0	9
Conceptual Analysis	9	3	6	4	4	1	0	2	5	0	0	0	0	2	23
Environmental Data Anal.	0	6	7	5	1	0	0	0	1	1	0	2	0	0	3
Economic Value	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypothetico-Deductive	1	0	2	1	1	1	0	0	0	1	0	0	0	0	0
Biochemical	4	3	8	3	0	0	0	0	0	3	0	0	0	0	2
Space Syntax	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Behavioural Response	0	2	2	1	0	0	0	0	1	1	0	0	0	0	1
Decision-making Modelling	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Diary Logs	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Method Development	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1
NA	3	5	4	4	0	2	1	0	0	1	0	0	0	0	14

Emerging technologies like VR and simulation are employed notably in the workplace, experimental settings, and education, reflecting growing interest in immersive and predictive tools. However, such methods remain underutilised in residential or hospitality contexts, where experiential interaction with nature may be equally relevant. Interviews, observational methods, and focus groups appear more often in education, residential, and healthcare typologies, but their overall use is modest. This highlights a methodological imbalance toward structured quantitative approaches over rich, contextual qualitative data.

Table 7 also shows a strong presence of literature reviews and conceptual frameworks, especially in studies without a specified typology (34 and 23, respectively), pointing to a significant portion of the field being either conceptual or cross-contextual in nature. Notably, 114 studies lacked a specific typology, reflecting either a theoretical orientation or a lack of applied focus, which limits the transferability of findings to concrete building types. Underrepresented typologies, such as prisons, religious spaces, transportation hubs, and space environments, are rarely paired with diverse methods, showing minimal exploration of biophilic design in these critical or extreme settings. The experimental room/lab typology is a methodological outlier, showing notable application of experimental (13) and VR-

based (6) approaches, highlighting its role in testing innovative biophilic interventions under controlled conditions [117,118].

Overall, the field heavily relies on a narrow range of methods in a few dominant typologies. To mature, biophilic design research would benefit from greater methodological diversity, especially the integration of participatory, physiological, and spatial analysis techniques and broader engagement with understudied building types, where nature–human interactions are equally vital but poorly understood.

Table 8 reveals a notable concentration of biophilic design parameters in institutional typologies. Within these typologies, a majority of studies frame biophilic design in a general or holistic manner, particularly in workplaces (49 studies), education settings (45), and healthcare facilities (32). However, partial parameter-focused approaches are also frequently employed, especially in the workplace (27) and healthcare (27) settings. This suggests a growing effort to both define biophilic design parameters comprehensively and examine the individual elements in applied contexts.

Table 8. Co-occurrence of typology and biophilic design parameter analysis.

	Healthcare Facilities	Educational Buildings	Workplaces	Residential Buildings	Hospitality Facilities	Retail/ Shopping	Prisons	Open Spaces	Constructions	Experimental Settings	Religious Buildings	Museum/ Pavilion	Transportation Hubs	Space Vehicle/Capsule	NA
General/ Holistic	32	45	49	27	15	10	1	4	8	5	1	1	2	3	67
Partial	27	20	27	13	7	5	0	4	3	11	1	2	0	0	42
Light/ Daylight	13	15	25	9	4	0	0	2	1	1	0	2	0	0	18
Natural View	23	12	19	5	3	1	0	1	0	5	0	0	0	0	16
Outdoor Green	7	11	4	3	3	2	0	6	1	0	0	0	0	0	9
Indoor/Balcony Green	12	13	15	9	4	6	0	1	0	6	0	1	0	0	13
Green Roof/Wall	3	2	4	1	1	0	0	0	1	0	0	0	0	0	9
Artificial	3	1	1	0	0	0	0	0	0	1	0	0	0	0	5
Biomimicry-Form	1	4	1	1	1	3	0	0	1	0	1	1	0	0	10
Material	7	9	10	7	1	3	0	2	3	2	0	1	0	0	5
Water	3	7	3	4	1	1	0	2	0	0	0	1	0	0	2
Colour	3	0	3	0	0	1	0	1	1	0	0	0	0	0	5
Fresh Air-Ventilation	5	10	7	5	1	0	0	0	0	0	0	0	0	0	9
Sensory Experiences	16	14	20	13	5	2	0	3	1	5	0	0	0	0	17
Thermal Comfort	1	5	8	5	0	0	0	1	0	1	0	0	0	0	6
Animal	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Prospect	3	5	3	2	1	2	0	0	0	0	0	0	0	0	2
Refuge	2	3	4	2	1	0	0	0	0	0	0	0	0	0	2
Curiosity	0	5	4	3	3	1	0	0	0	1	0	0	0	0	2

Among the biophilic parameters, light/daylight, views of nature, indoor greenery, and sensory experiences are most frequently addressed. These appear predominantly in workplace and education settings [102,103], indicating a sustained focus on environmental comfort and perceptual enhancement in spaces designed for productivity and learning. In contrast, outdoor greenery, natural materials, and green roofs/walls are discussed less often and are more typology-specific, appearing in education, residential, and urban contexts [119–121].

Notably, the table highlights a significant underrepresentation of psychological and experiential parameters, such as prospect, refuge, and curiosity, which are core to the biophilic design hypothesis [57,58,122]. These parameters appear sporadically across the typologies and are almost entirely absent in many. Their limited integration suggests that

the affective and cognitive dimensions of biophilic experience remain underexplored in built environment research.

The residential (27), hospitality (15), and retail (10) sectors show moderate engagement with biophilic parameters but remain underrepresented compared to institutional typologies. More marginal contexts, like prisons, public transport, space capsules, and sanctuaries, show minimal coverage, highlighting biophilic design's nascent or neglected application in these critical and often high-stress environments. Interestingly, experimental settings display relatively diverse parameter engagement, including views (five), sensory experience (five), and thermal comfort (one), pointing to their role as testing grounds for biophilic interventions [117,118].

The findings strongly focus on visual and sensory parameters within formal institutional buildings, with limited attention to emotional, ecological, and symbolic biophilic parameters. This indicates both the maturity of certain research areas and the substantial opportunity for expansion into underexplored parameters and typologies.

4.2.6. COVID-19 Focus

The analysis of the included studies showed that only 17 studies take the COVID-19 pandemic into account (Figure 15). Among the 17 studies that explicitly addressed the COVID-19 pandemic, a clear emphasis is observed on domestic and occupational environments [123–127]. Residential buildings (seven studies) and workplaces (four studies) were the most frequently studied typologies [124,127], reflecting how the pandemic reshaped daily life by centring activities around the home and remote or hybrid work settings. This focus aligns with increased awareness of indoor environmental quality and the psychological effects of prolonged confinement.

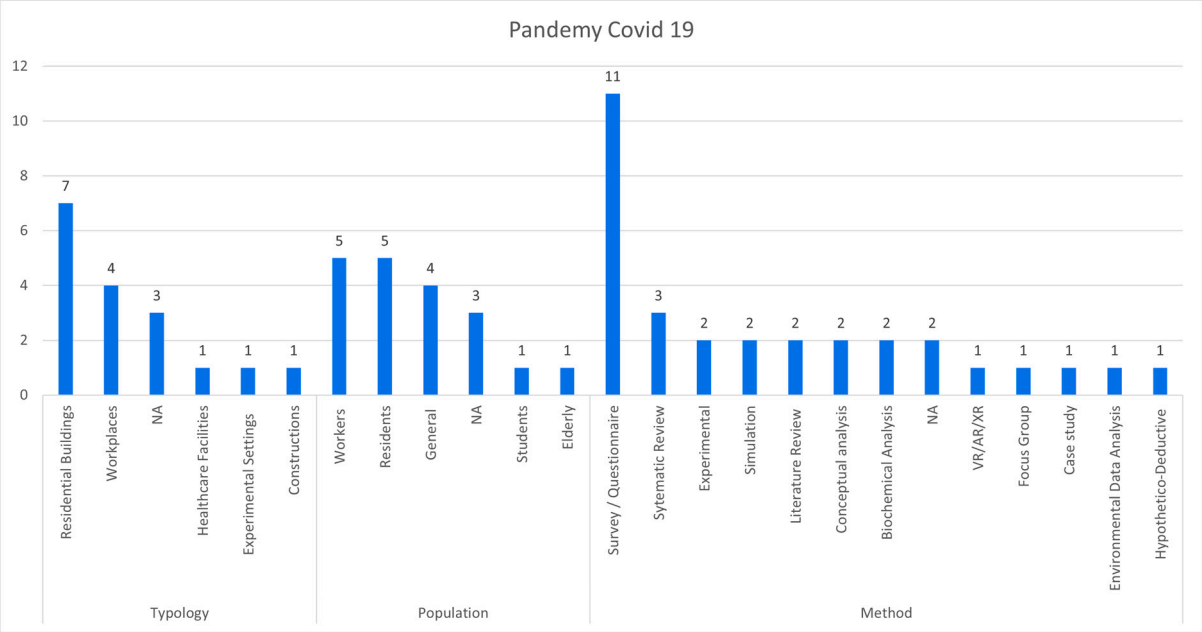

Figure 15. Analysis of COVID-19-related studies by typology, population and method.

Regarding user populations, staff, workers and residents were equally prioritised (five studies each), indicating concern for both productivity and well-being in home and professional settings during lockdowns [126]. The general population also received notable attention (four studies), likely reflecting the pandemic's widespread societal impact. However, vulnerable groups such as older adults and students were only minimally repre-

sented (one study each), suggesting an under-exploitation of biophilic design's potential for supporting these at-risk demographics during crises.

Methodologically, survey-based research dominated the field (11 studies), highlighting the accessibility and speed of this approach during socially distanced conditions. However, this reliance may also limit depth and contextual richness. A range of other methods, systematic reviews (three), experimental and simulation techniques (two each), and conceptual frameworks (two), were applied less frequently, indicating some methodological diversity. VR, biochemical analysis, and case studies appeared simultaneously, suggesting exploratory efforts to innovate under new constraints. The diversity of methods and typologies suggests an adaptive response by the research community to evolving spatial and social conditions during the pandemic. However, the relatively small number of studies and the limited focus on high-risk populations and complex public typologies (e.g., healthcare, transportation, education) point to a need for further targeted research on biophilic interventions in crisis contexts.

4.3. Theory, Heritage, Standards/Regulations, and Education

While much of the biophilic design research focuses on practical applications within architectural and interior environments, the field also encompasses broader perspectives on theory building, policy, heritage, and education. These dimensions are essential to understanding how biophilic principles are interpreted, taught, and embedded in regulatory frameworks [6]. The following analysis (Table 9) examines how these less practice-oriented yet influential areas have been investigated in the literature, revealing both their contributions and current limitations.

Only 12 studies employed heritage or traditional buildings as case studies, reflecting limited engagement with this typology in biophilic design research [115,128,129]. The most common method was observation/site visits (four studies), followed by conceptual frameworks (three) and content analysis (two). Other methods, including surveys and systematic reviews, appeared only once or twice. Notably, no studies used experimental, simulation, or technology-based methods. This indicates a qualitative, theory-driven focus, with significant potential to expand methodological diversity in future research. A total of 46 studies explored biophilic design through the lens of building standards, regulations, and policy [130–133]. Among these, the most commonly employed methods were literature reviews (16 studies) and conceptual framework analyses (13 studies), suggesting a strong theoretical orientation in how biophilic principles intersect with regulatory frameworks. Survey questionnaires (nine) and case studies (seven) also featured prominently, indicating some degree of empirical engagement. In contrast, heritage and traditional building studies (12 total) relied more on site visits (4 studies) and conceptual frameworks (3), with limited use of other methods. Experimental, simulation, and technological methods (e.g., VR, AI) were largely absent in both domains. Although research on policy and standards in biophilic design demonstrates growing interest, it remains heavily skewed toward qualitative and conceptual methodologies. The limited methodological diversity, particularly in heritage contexts, highlights an opportunity for future studies to adopt more empirical and interdisciplinary approaches.

Among the 80 studies that approached biophilic design from a theoretical perspective, conceptual frameworks and literature reviews were the dominant methods, used in 25 and 23 studies, respectively. Case studies (18) and surveys (21) also played a notable role, indicating some overlap between theory development and empirical inquiry. In contrast, practical methods such as experimental designs (12) and simulations (2) were less frequently used, suggesting that theory building in the field is still largely shaped by secondary data and conceptual thinking.

Table 9. Methodologies in studies related to theory, heritage, standards/regulations, and education.

	Heritage	Standards Regulations	Theory (General)	Academic Education
Survey/Questionnaire	2	9	21	11
Experimental	0	4	12	8
VR/AR/XR	0	1	1	3
Simulation	0	2	2	0
Interview	0	5	4	2
Focus Group	0	1	1	4
Observation	4	6	10	4
AI/Machine Learning	0	0	1	1
Bibliometric	0	0	0	0
Systematic Review	1	2	12	0
Content Analysis	2	4	4	1
Literature Review	1	16	23	6
Prototype Development	1	2	1	2
Participatory Design	0	1	0	2
Case Study	1	7	18	6
Conceptual Analysis	3	13	25	4
Environmental Data Anal.	0	3	4	4
Economic Value	0	0	0	1
Hypothetico-Deductive	0	0	4	0
Biochemical	0	2	2	2
Space Syntax	0	0	0	0
Behavioural Response	0	0	1	1
Decision-making Modelling	0	0	0	0
Diary Logs	0	0	1	0
Method Development	0	1	0	1
NA	2	1	4	0

Thirty-two studies reported academic education techniques, particularly focusing on biophilic design education in architecture studios. This body of research has a clear preference for empirical and exploratory methods. Surveys (11), experimental studies (8), and focus groups or workshops (4) are the most frequently used, reflecting a strong emphasis on capturing experiential feedback and fostering interactive learning [134–137]. Case studies (six), literature reviews (six), and conceptual frameworks (four) also show the field's solid theoretical foundations. Although emerging, advanced tools such as VR and AI are beginning to be applied, indicating growing innovation in pedagogical methods, this distribution highlights a practice-oriented yet theoretically grounded approach to biophilic design education.

4.4. Biophilic Design Parameters

Biophilic design parameters should be considered holistically in practice, with all relevant parameters working harmoniously to create a truly biophilic space [5,60]. However, studies that adopt such a comprehensive approach are relatively rare. This review examined 435 papers, focusing primarily on abstracts, where it is often difficult to determine whether all parameters were addressed holistically. Therefore, studies that referred to biophilic design in a general or holistic sense were categorised under the "general/holistic" group,

comprising 259 papers. In contrast, 157 studies focused in depth on specific biophilic parameters rather than addressing the full range.

4.4.1. Parameter-Focused Studies

Figure 16 illustrates the distribution of biophilic design parameters examined in 157 studies that focused on specific parameters rather than adopting a holistic approach. Greenery emerged as the most emphasised category, with 95 studies investigating indoor/balcony plants (47), outdoor green areas (29), and green roofs or walls (19). This preference suggests a strong visual and spatial association between biophilic design and greenery, possibly due to its tangible and easily implementable nature in built environments [57]. Other frequently addressed parameters include views of natural scenery (54 studies), sensory experiences (48), and natural light/daylight (45), reinforcing the importance of environmental stimuli in supporting user well-being [138]. Moderate attention was given to material use, fresh air/ventilation, and thermal comfort.

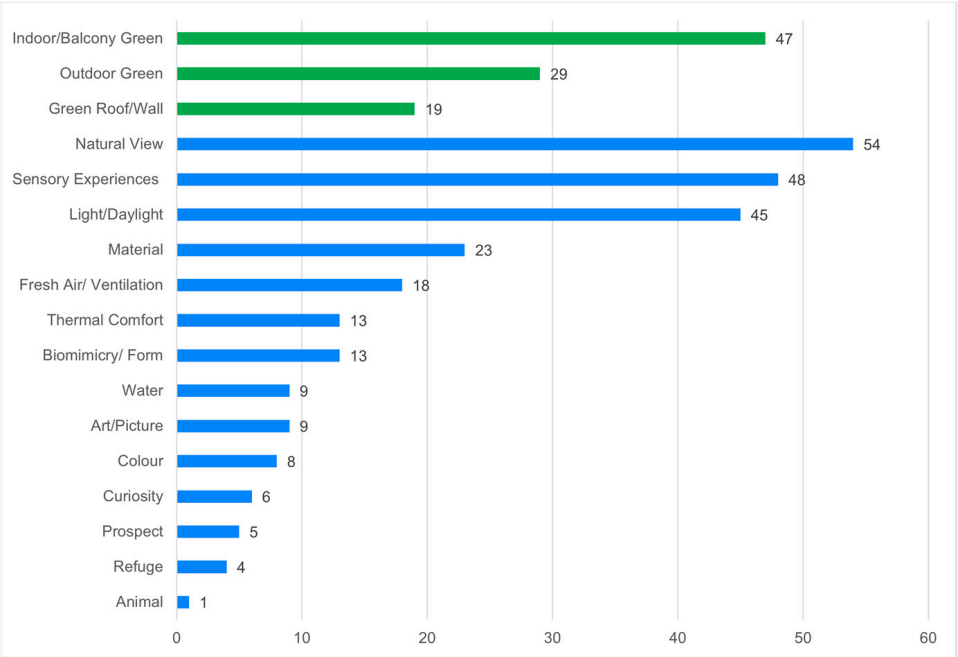

Figure 16. Frequency of parameters in parameter-focused studies.

Notably, artificial representations of nature, such as images, artworks, or simulated environments, were examined in nine studies. While this number is relatively low, these parameters are particularly significant in settings where real nature cannot be integrated due to spatial, climatic, or operational constraints [139]. Such strategies offer valuable alternatives for introducing biophilic qualities, especially in enclosed, extreme or high-density environments.

Parameters such as natural patterns, water features, and thermal comfort were mentioned occasionally, while psychological aspects like curiosity, prospect, and refuge received minimal attention. Only one study addressed animal presence, highlighting a significant gap in this area. These findings suggest that most parameter-focused studies prioritise physical and visual parameters, while the psychological and multisensory parameters of biophilic design remain underexplored.

4.4.2. Most Frequently Mentioned Parameters Overall

Figure 17 presents the overall frequency of specific biophilic design parameters mentioned across all 435 reviewed abstracts. Compared to the subset of 157 parameter-specific studies, this comprehensive view reveals broader trends in the literature.

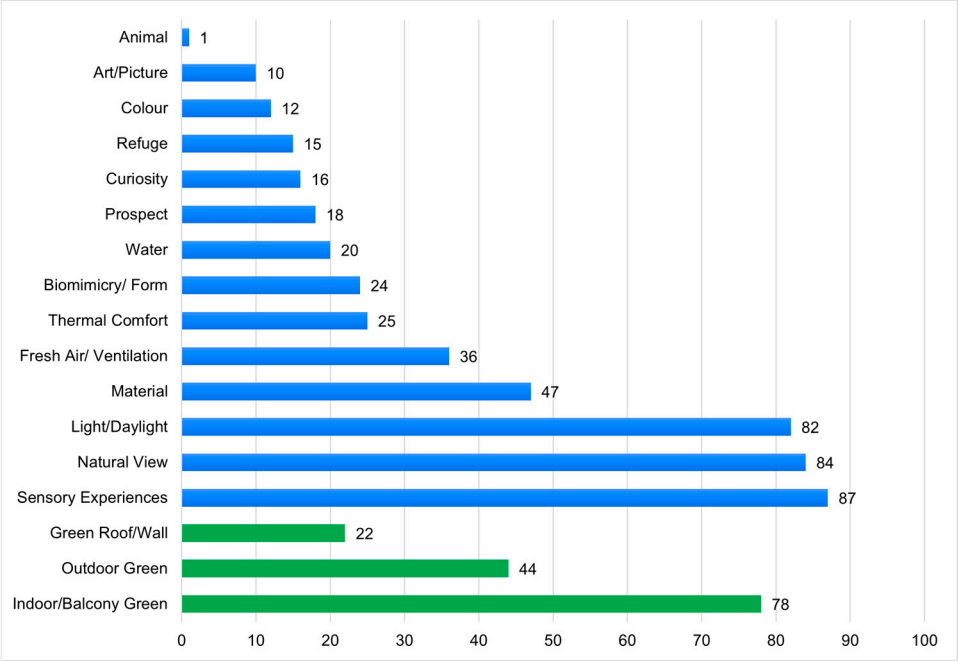

Figure 17. Frequency of parameters in all studies.

Greenery remains the most dominant category, with a cumulative total of 144 mentions across indoor/balcony green (79), outdoor green (39), and green roofs/walls (26). Sensory experiences (88), views of natural scenery (85), and natural light/daylight (82) are also among the top-referenced parameters, suggesting a continued prioritisation of environmental stimuli that engage the senses and foster connection with nature. Compared to the partial-focused parameters, the overall dataset shows a broader, more even distribution across a wider array of parameters, including material use (47), fresh air/ventilation (36), and thermal comfort (30), all crucial for occupant well-being but less emphasised in narrowly focused studies. Moreover, psychological parameters, including prospect (18), refuge (16), curiosity (17), and especially animal presence (1), remain significantly underrepresented across both focused and general research.

In summary, while greenery and sensory connections are central to the biophilic design literature, there is a consistent gap in addressing abstract, representational, or psychological parameters. This suggests a need for more comprehensive and balanced research that includes less tangible, yet equally important, aspects of human–nature interaction.

The prominence of daylight, greenery, and visual access to natural elements across the reviewed studies strongly aligns with the principles of Attention Restoration Theory and Stress Recovery Theory. These frameworks suggest that visual connection to nature fosters cognitive restoration and reduces physiological stress, findings that are well supported by the dominant design features observed in biophilic research [8,15,21]. Similarly, the emphasis on natural views and organic materials corresponds to Ulrich's claim that contact with natural elements promotes faster stress recovery and well-being [8].

However, despite alignment with foundational theories like ART and SRT, the literature reveals a clear imbalance between sensory-focused and neuroscience-informed approaches. Multisensory strategies, such as visual, auditory, and tactile parameters, are

widely studied and integrated into biophilic design, supporting the idea that rich sensory environments promote psychological comfort and cognitive restoration [53,116]. In contrast, neuroscience-informed research remains scarce. Very few studies employ neurophysiological tools or investigate the brain-based responses to biophilic environments through methods like EEG, fMRI, or biometric tracking. This gap limits the field's ability to empirically validate and refine existing theoretical frameworks using objective cognitive and emotional data. To evolve biophilic design as a truly intelligent and adaptive practice, future research must build stronger bridges between multisensory design and neuroarchitectural validation.

Overall, the content analysis highlights key patterns and limitations in the current biophilic design literature, including a strong focus on institutional settings, common reliance on subjective methods, underrepresentation of specific user groups, building typologies, and psychological parameters. While the field demonstrates growing interest and methodological diversity, significant gaps in context-specific application, interdisciplinary integration, and holistic parameter use remain. These findings provide a foundation for identifying broader research trends, existing gaps, and opportunities for future development, as discussed in the following section.

5. Trends, Gaps, and Future Directions in Biophilic Design Research

The findings from the bibliometric and structured content analyses of 435 peer-reviewed publications confirm that biophilic design has undergone a substantial evolution, progressing from a marginal topic to a prominent interdisciplinary research domain. This expansion reflects broader shifts in architectural and environmental discourse, especially the growing recognition of the built environment's impact on health, well-being, and ecological balance. This section outlines significant patterns observed in the existing literature, identifies persistent limitations, and proposes actionable directions for future research.

5.1. Emerging Research Trends

This study reveals several key patterns illustrating how biophilic design research has evolved in recent years. These trends reflect not only a growing scholarly interest in nature-integrated design but also the diversification of research themes, methods, and institutional contexts. By identifying where and how biophilic design is most actively studied, the findings summarised in Table 10 highlight the research trends, dominant typologies, methodological preferences, and interdisciplinary shifts that characterise the current state of the field.

Table 10. Trends in biophilic design research in the built environment.

Trend	Description
Acceleration of Research Post-2020	Research output sharply increased after 2019, reflecting growing concerns about health and well-being in indoor environments due to the COVID-19 pandemic.
Interdisciplinary Expansion	Research spans architecture, psychology, public health, sustainability, and digital technology, with converging interests in VR, mental health, and ecological outcomes.
Dominance of Institutional Typologies	Workplaces, schools, and hospitals are most studied due to their direct link with measurable cognitive, emotional, and productivity benefits.
Empirical Orientation	Surveys and experimental designs dominate, emphasizing subjective user perceptions and measurable environmental satisfaction.

Table 10. *Cont.*

Trend	Description
Technological Integration	The use of VR, simulation, and biometric methods is increasing, albeit still limited, and offers new modalities for immersive and precise evaluation.
Rapid Mainstreaming Post-2019	Publication output rose sharply after 2019, driven by pandemic-related interest in indoor environments and wellness-focused design.
Global and Interdisciplinary Expansion	While early research was concentrated in North America and Europe, recent growth in China, Malaysia, and Australia highlights global uptake. Research themes now integrate environmental psychology, sustainability, and digital technologies.
Institutional and Workplace Dominance	Workplaces, schools, and healthcare buildings continue to dominate in both empirical focus and typological representation.
Surveys and Experiments Prevail	User-centred studies heavily rely on perception-based tools (e.g., surveys, experiments), particularly in institutional contexts.
Emerging Use of VR/AR and Simulation	Though limited, interest in immersive and predictive technologies is growing, especially in education and experimental settings.
Greenery and Visual Comfort Prioritized	Greenery, daylight, and views of nature remain the most frequently studied parameters, often linked to productivity and well-being.

5.2. Gaps and Limitations in the Current Literature

Despite the rapid expansion of biophilic design research, several critical gaps and structural limitations remain evident across the literature. These deficiencies relate not only to methodological consistency and thematic scope but also to issues of inclusivity, contextual relevance, and interdisciplinary integration. Table 11 outlines the most pressing omissions that constrain the field's ability to generate comprehensive, generalizable, and applied knowledge.

Table 11. Research gaps in the biophilic design field in the built environment.

Gap	Description
Lack of Climate-Specific Frameworks	Only 56 studies mention climate; there is a significant lack of location-sensitive design principles.
Cultural and Heritage Underrepresentation	Cultural references are scarce, with only 15 studies exploring traditional or symbolic meanings of nature.
User Group Imbalance	Research largely neglects elderly, neurodiverse, and marginalised communities; the focus is primarily on institutional populations.
Typological Narrowness	Critical building types like retail, transit, religious spaces, and detention facilities are underexplored.
Overlooked Psychological Parameters	Despite their theoretical importance, the Prospect, refuge, and symbolic representations of nature are seldom addressed.
Fragmented Research Networks	Most research is regional, with few extensive or interdisciplinary collaborations that could support standardisation and scalability.
Underutilization of Advanced Technologies	Technological tools such as VR/AR, simulation, biometric tracking, and AI are still rarely employed in biophilic design research.

Table 11. *Cont.*

Gap	Description
Lack of Experimental and Neuroscience-Informed Research	Experimental exploration of the field remains insufficient. Among the few studies engaging with neuroarchitecture, only two employed experimental methods, highlighting a substantial gap in the integration of neuroscience-based experimentation
Neglected Cultural Contexts	Only 15 acknowledge cultural context, revealing a serious contextual blind spot.
Lack of Contextual Diversity	Despite the global relevance of biophilic design, the literature is heavily concentrated in Western regions. There is minimal representation from Global South contexts.
Underrepresentation of Critical Typologies	Prisons, transit hubs, sanctuaries, and extreme environments (e.g., space habitats) are virtually absent, despite their high-stress nature.
Psychological and Symbolic Parameters Overlooked	Refuge, curiosity, prospect, and animal presence are rarely examined, despite being central to biophilic theory.
Minimal Focus on Vulnerable Populations	Children, older adults, neurodivergent individuals, and marginalised communities are consistently understudied across all typologies.
Fragmented Collaboration and Regional Isolation	Most author teams are small (2–4 people) and regionally clustered, limiting methodological standardisation and international relevance.
Overreliance on Holistic but Vague Mentions	Two hundred fifty-nine studies refer to biophilic design in general terms, but only a subset of 157 focus in depth on specific, measurable parameters.

5.3. Future Directions for Biophilic Design Research

Building on the identified trends and gaps, Table 12 outlines key priorities for advancing biophilic design as a more inclusive, evidence-based, and context-responsive discipline. These future directions emphasise methodological innovation, expanded typological and demographic coverage, and a stronger integration of cultural, climatic, and technological dimensions. Although they were not applied in the current study, additional triangulation methods, such as Latent Dirichlet Allocation (LDA) topic modelling or time-series clustering, could further validate thematic trends and identify the evolution of emerging or declining subfields. Future research may benefit from integrating these approaches to strengthen the robustness and foresight of bibliometric analyses.

Table 12. Future directions of biophilic design research in the built environment.

Direction	Description
Climate-Responsive Design	Develop frameworks tailored to environmental zones, with adaptive use of light, vegetation, and thermal features.
Cultural Integration	Incorporate cultural narratives and regional traditions into design strategies; address intangible heritage through space.
Inclusive Research	Focus on the needs of elderly, cognitively diverse, and underserved users via participatory and ethnographic approaches.
Expand Building Typologies	Investigate transit, retail, sanctuary, and correctional facilities to improve psychological well-being in neglected contexts.

Table 12. *Cont.*

Direction	Description
Longitudinal and Mixed Methods	Combine physiological, spatial, and self-report tools over time to measure effects holistically.
Advanced Technologies	Employ AI, wearables, and real-time feedback systems to inform design and measure performance in dynamic settings.
Adaptive Systems and Smart Buildings	Apply biophilic and neuroarchitectural insights to develop intelligent buildings with adaptive systems that respond to user needs through sensors, neurofeedback, and context-aware technologies, enhancing well-being and performance.
Global Collaboration	Build international partnerships to ensure metric standardisation, cultural applicability, and data-driven policymaking.
Incorporate Cultural and Heritage-Sensitive Design	Include spiritual, symbolic, and vernacular aspects of nature integration, particularly in heritage buildings and sacred spaces.
Expand to High-Stress and Underserved Typologies	Explore biophilic strategies in prisons, public transportation, religious spaces, and housing for vulnerable populations.
Expand Experimental Exploration	Increase the use of experimental methods to empirically assess the effects of biophilic and neuroarchitectural design elements on human cognition, emotion, and physiology, enabling stronger causal inferences and evidence-based practice. Use tools such as brain imaging, biometric sensors, and neurocognitive performance metrics.
Bridge Empirical Gaps with Longitudinal Mixed Methods	Combine biometric data (e.g., cortisol, HRV) and spatial analysis with qualitative interviews to understand long-term effects.
Integrate Neglected Parameters	Advance multisensory and psychological dimensions such as soundscapes, tactile materials, refuge, and curiosity.
Strengthen Cross-Sectoral and Global Collaboration	Build international, interdisciplinary networks to standardise biophilic indicators, improve comparative validity, and co-develop policy frameworks.

5.4. Limitations of This Study

While the findings presented in this review offer valuable insights into the state of biophilic design research, several limitations must be acknowledged. These relate to the scope of data collection, methodological choices, and the inherent challenges of working with abstract-level information. Recognising these limitations is an essential step for accurately interpreting the findings and identifying opportunities for improvement in future research. These limitations provide a foundation for future meta-reviews and call for broader inclusion across linguistic, disciplinary, and geographic boundaries.

One key limitation is the reliance on abstracts for content coding. Abstracts often lack the methodological or conceptual detail found in full texts, which may lead to the underrepresentation of certain research aspects. Additionally, this review only includes English-language, peer-reviewed journal articles indexed in Scopus and Web of Science. This may exclude valuable contributions from regional studies or the grey literature, resulting in language and access bias. Furthermore, affiliation data in Web of Science and Scopus may sometimes be incomplete or inaccurately assigned, which can affect the reliability of country-level publication and collaboration analyses [140,141]. Moreover, the availability and standardisation of abstract and keyword metadata in Web of Science and Scopus can vary across journals and publication years [142], which may limit the consistency and completeness of keyword-based analyses in this study.

The scope of the review also narrows its contextual focus by excluding studies centred on urban planning or large-scale landscapes, unless they are clearly linked to architectural or

interior design. Furthermore, the literature search was conducted in March 2025, meaning that more recent studies and innovations published after this date were not included.

Additionally, the exclusive focus on peer-reviewed English-language journal articles indexed in Scopus and Web of Science may introduce language and publication bias [67], potentially overlooking valuable grey literature and region-specific studies. Greater inclusion of non-English sources, full-text analysis, and interdisciplinary coverage will be essential to capture a more complete picture of biophilic design research worldwide. Also, the research still carries a degree of subjectivity that may influence inclusion decisions, although the abstract screening process followed a rigorous double-review protocol with panel resolution. In summary, while this study offers a comprehensive overview, its abstract-based coding, language restrictions, and source limitations point to areas where future reviews can expand and improve.

6. Conclusions

This study offers a comprehensive and methodologically innovative overview of biophilic design research in the built environment. Integrating bibliometric mapping with structured content analysis across 435 peer-reviewed studies moves beyond surface-level trends to critically examine the conceptual, methodological, and contextual contours of the field. Unlike previous reviews, this study applies a two-step screening process, first manually filtering abstracts for architectural relevance, then combining quantitative bibliometric indicators with qualitative coding across typologies, users, climate zones, and design parameters. This approach allows for both macro-level mapping and micro-level insight into applying and interpreting biophilic design principles.

The findings show that while biophilic design has matured into a mainstream research topic, especially after 2019, the field remains unevenly developed. Institutional typologies (workplaces, schools, healthcare) dominate the literature, while critical environments such as transit hubs, correctional facilities, religious spaces, and community-based settings remain severely underexplored. The same imbalance exists among user groups, with staff, students, and patients widely studied, but older adults, neurodiverse individuals, and marginalised populations are largely overlooked.

Methodologically, the field is still anchored in subjective, perception-based tools such as surveys and interviews. Although a growing number of studies incorporate immersive technologies like VR, simulation, and environmental sensors, these remain underutilised. Importantly, despite increasing interest in the neuroscientific basis of architectural experience, only a few studies explicitly engage with neuroarchitecture or employ experimental methods to examine cognitive and emotional responses to biophilic environments. This represents a missed opportunity to deepen empirical understanding through biometric sensing, brain imaging, and physiological stress measurement tools. This review also reveals a consistent overemphasis on greenery, light, and views, while psychological, symbolic, and multisensory parameters remain underused.

To advance the field in line with the goals of intelligent, health-supportive architecture, future research should prioritise context-sensitive, climate-responsive, and culturally grounded biophilic strategies. Equally important is the need to expand experimental exploration, integrate neuroscience-based methods, and leverage advanced technologies to better understand user experiences and optimise design outcomes. Achieving greater typological and demographic inclusivity, alongside applying hybrid and data-driven approaches, will be essential for making biophilic design more evidence-based, scalable, and globally relevant. Moreover, stronger international and interdisciplinary collaboration is needed to unify currently fragmented efforts and co-develop robust standards that can guide both research and practice. Ultimately, such interdisciplinary innovation will be

key to creating adaptive environments that align with human neurological, cognitive, and emotional needs.

This study not only charts the evolution of biophilic design but also offers a replicable model for knowledge synthesis in architecture, environmental psychology, and design research. It provides a strategic roadmap for researchers, practitioners, and educators seeking to harmonise nature, mind, and technology in the development of developing evidence-based, inclusive, and future-ready built environments.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/buildings15142516/s1, Table S1: List of included 435 articles; Table S2: Data extraction tool and descriptive protocol.

Author Contributions: B.H.T.: conceptualisation, data curation, formal analysis, visualisation, writing—original draft. G.I.T.: conceptualisation, data curation, formal analysis, methodology, writing—original draft. Z.N.D.: software, data curation, formal analysis, visualisation, writing—review and editing. H.S.O.: data curation, formal analysis, visualisation. All authors have read and agreed to the published version of the manuscript.

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