Biophilia Upscaling

A Systematic Literature Review Based on a Three-Metric Approach

Lefosse, Deborah; van Timmeren, Arjan; Ratti, Carlo

DOI
10.3390/su152215702

Publication date
2023

Document Version
Final published version

Published in
Sustainability

Citation (APA)
Lefosse, D., van Timmeren, A., & Ratti, C. (2023). Biophilia Upscaling: A Systematic Literature Review Based on a Three-Metric Approach. *Sustainability*, *15*(22), Article 15702. https://doi.org/10.3390/su152215702

sustainability

Review

Biophilia Upscaling: A Systematic Literature Review Based on a Three-Metric Approach

Deborah Lefosse [1,2,*], Arjan van Timmeren [1] and Carlo Ratti [2]

1 Environmental Technology & Design, Department of Urbanism, Faculty of Architecture and the Built Environment, Delft University of Technology, Julianalaan 134, 2628 BL Delft, The Netherlands
2 Senseable City Lab, Department of Urban Studies and Planning, School of Architecture + Planning, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
* Correspondence: dlefosse@mit.edu or d.c.lefosse@tudelft.nl

Abstract: In response to socio-ecological challenges, cities around the world are implementing greenification and urban forestry. While these strategies contribute to reducing the ecological footprint, they often overlook various social implications. This explains the increasing global attention to Biophilia, which emphasizes human–nature interaction to enhance the quality of urban life. Despite its historical roots spanning centuries, Biophilia is still considered an emerging research field, as shown by debate on evidence-based research and measurement of its multidimensional impacts. Although the beneficial effects of Biophilic Design (BD) are well documented thanks to the small-scale and immediate outcomes, the long-term potential of Biophilic Urbanism (BU) offers less evidence, limiting its utilization and investment. This paper provides a comprehensive theoretical-practical framework on Biophilia, BD, and BU through a 60-year systematic literature review based on a three-metric approach (quality, quantity, and application). Investigating concepts and practices, we delve into biophilic effects on humans and urban livability, analyze tools to measure them, and explore methods to translate them into the built environment. In spite of the growing body of studies and advancements in the last decade, our review findings highlight the need for further insights, especially regarding BU. The study aims to promote Biophilia Upscaling as a strategy to maximize its direct and indirect benefits across urban scales, thereby promoting BU and expediting a paradigm shift in city planning. In metropolises conceived as bioregional systems, where nature plays a key role in ensuring ecological services and citizens' well-being, BU can assist designers, planners, and city makers in addressing the urban agenda toward higher environmental and social standards.

Keywords: biophilia; biophilic design; biophilic urbanism; biophilia upscaling; literature review

check for updates

Citation: Lefosse, D.; van Timmeren, A.; Ratti, C. Biophilia Upscaling: A Systematic Literature Review Based on a Three-Metric Approach. *Sustainability* **2023**, *15*, 15702. https://doi.org/10.3390/su152215702

Academic Editor: Nikos A. Salingaros

Received: 2 October 2023
Revised: 26 October 2023
Accepted: 27 October 2023
Published: 7 November 2023

1. Introduction

Rapid and unprecedented urbanization affecting the globe in recent decades is widely recognized as undermining human health, social stability, and economic prosperity [1]. Moreover, uncontrolled densification has led to a loss of urban green spaces and biodiversity [2]. In response to significant socio-ecological challenges, cities worldwide are implementing programs oriented to healthier design, sustainable planning, and greenification [3]. An incremental application of nature in the city through Nature-Based Solutions (NBSs) is turning the concrete jungle into an urban forest, reconnecting the anthropogenic habitat to the biosphere [4]. Among NBSs, Green Infrastructures gained strategic resonance expanding landscape planning into a more robust urban design thinking [5] and acting as "projective ecologies" of green spaces [6]. All such actions are efficient at reducing the environmental impact and achieving ecosystem service goals, but they neglect various social implications, notably the effects of nature on the health and well-being of millions worldwide, who suffered from its absence or enforced distance during the COVID-19 pandemic [7]. This circumstance unveiled not only the vulnerable interdependencies between humans and nature but also the reciprocity between planet resource consumption and threats posed by cities, including deforestation, biodiversity loss, and climate change [8].

Against the relentless migration trend from the countryside to the cities, research indicates that rural living is preferable to an urban lifestyle due to the better environmental quality that assures mental and physical health [9]. Due to modern habits and a rising technology addiction, we spend 90% of our time indoors. Consequently, recent studies unanimously characterize us as an "indoor generation" [10]. Conversely, more and more citizens pay to be immersed in nature, associating it with a restorative praxis for personal well-being [11]. This explains the increasing global attention to Biophilia, which relies on the interaction between humans and nature to enhance urban livability, face climate change, and bolster urban sustainability and resilience [12]. Since the late 1960s, Biophilia has grown in popularity as a love for life and an innate man's need to affiliate with all living forms and systems [13]. The concept of Biophilia advances the idea that contact with nature plays a fundamental role in human physical and mental well-being [14]. Firstly pioneered as a genetic-oriented process [15], it was further elaborated in scientific theory—known as Biophilic Hypothesis (BET)—built upon the multidisciplinary evidence [14]. Later, Biophilic Design (BD) was introduced as a novel design language aimed at transposing the BET principles into the built environment [16–18]. Conceived as complementary support to green architecture, BD offers an emotional way to enjoy the space, maximizing nature's contribution to making our lives healthier, happier, and more productive [19]. BD was very well received by the scientific community owing to an abundance of studies substantiating the impacts of Biophilia on societal, environmental, and economic systems [20]. In slightly more than a decade, BET was also extended to the cityscape, where the need for daily human–nature contact is not optional but essential to ensure a higher quality of life and preserve biodiversity [21]. The application of Biophilia within the urban context is the legacy of a long-lasting intellectual movement deeply rooted in theories and practices intended to integrate nature and design. Over time, this movement has evolved, associating Biophilia with contemporary concepts, such as Green Urbanism [22], sustainability [12], and smart cities [23].

From its initial applications dating back centuries to the newer global movements, Biophilia continues to be considered an emerging research field, and there remain limitations in broader and intersectoral progress [24]. Among the noteworthy issues, scientific objectivity, measurability, and the upscaling process demand further insights. While the concept of Biophilia has gained recognition and support, its scientific foundation is still subjected to ongoing debate, due to the complexity inherent in basic assumptions, such as the human–nature interactions. Since Biophilia involves the emotional sphere, its inherently subjective nature raises scientific inquiries. As hybrid disciplines, design, architecture, and planning are the result of both technological quantities and artistic qualities, but not all spatial qualities are readily quantifiable or standardized [25]. Additionally, recent studies confirmed the complexity of addressing the multidimensional effects of green space, necessitating the integration of diverse research disciplines: the high heterogeneity of study designs, exposure assessments, and outcomes underscore the call for greater rigor, precision, and robustness [26]. Regarding practical application, the beneficial effects of Biophilic Design (BD) have been extensively documented, primarily due to their small-scale and immediate outcomes. Furthermore, BD is substantiated by applied sciences, which illustrate how mathematical models, specifically fractals underlying Biophilia, have significant practical implications for enhancing the built environment and the well-being of its occupants [27]. Yet, although the beneficial effects of Biophilic Design (BD) are well documented thanks to the small-scale and immediate outcomes, the long-term potential of Biophilic Urbanism (BU) offers less evidence, limiting its utilization and investment. Meanwhile, BU is taking place in an increasing number of metropolises, where nature plays a key role in maintaining ecological continuity and safeguarding the local identity within bioregional systems [26].

The paper addresses these knowledge gaps through a 60-year systematic literature review based on disciplinary, metric, and spatial dimensions. It aims to advance the state of the art and provide a comprehensive theoretical-practical framework on Biophilia, BD, and BU as an applied science able to inform architecture and urban planning. Thus, it tries to answer the following research questions (RQs):

RQ1: What is Biophilia and what are its effects on humans and urban livability?
RQ2: How do we measure them?
RQ3: How do we experience them in the built environment?

The paper is organized as follows. After outlining materials and methods used in the review process (Section 2), Biophilia is reviewed as an evolving concept through its various definitions (Section 3). The related effects (biophilic effects) on people and urban livability are analyzed using metrics (Section 4). Finally, the results are discussed to highlight the potential limitations of research as a baseline for future insights (Sections 5 and 6).

2. Materials and Methods

2.1. Review Process

We have conducted a Systematic Literature Review (SLR) to scan nearly six decades of literature; such a method is particularly advisable in urban studies given their interdisciplinary nature [28]. This SLR adheres to both the PRISMA protocol and theory [29]. Additionally, we followed city-related SLR guidelines that align with the research field, metric analysis, and selection criteria [30]. As depicted in Figure 1, the search and review process ran through the following four stages.

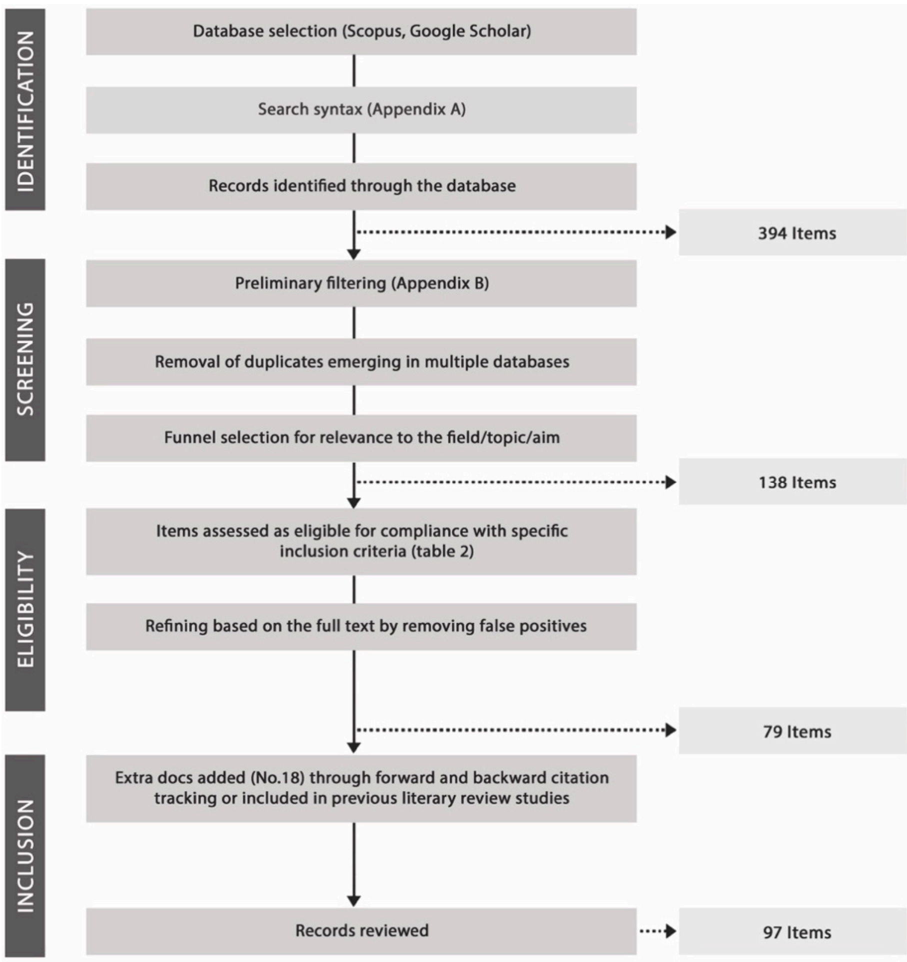

Figure 1. Selection process flow diagram (PRISMA).

Stage 1. Identification: After establishing review objectives and criteria, we selected publications on Scopus and Google Scholar using search tools such as the title, abstract, and keywords. To refine the query, we applied a reproducible bibliographic syntax to both datasets, employing four main keywords: Biophilia; biophilic benefit; Biophilic Design; and Biophilic Urbanism. They were linked to urban-related subjects to create specific word combinations (up to three words). As an effective method for information retrieval, a Boolean search allowed us to maximize outputs by combining them with the most common operators (Appendix A). The rough literature pool yielded 394 records from the two datasets.

Stage 2. Screening: We manually screened the fetching items in three steps. Initially, many were excluded for not meeting preliminary filters associated with publication typologies, language, timing, and disciplinary relevance (Appendix B). Then, we removed duplicates emerging in multiple databases. Lastly, a funnel title-oriented check led us to consider only the literature highly relevant to the research aim.

Stage 3. Eligibility: A set of particular inclusion criteria was developed to facilitate the subsequent selection via abstract reading (Table 1). To empower later analysis, documents were categorized into two research approaches (theoretical and practical) and three metric groups (quality, quantity, and application). Items complying with inclusion criteria were subjected to full-text reading to remove false positives.

Stage 4. Inclusion: To include seminal literary works not covered by peer-reviewed datasets, we identified extra items through forward and backward tracing of references. This was needed for non-indexed books or older publications, crucial in supporting the theoretic apparatus. At the end of this process, 97 records were retained for SLR. They span from 1964 to 2022, even though analysis focused on items from the mid-1980s when Biophilia was founded as a new research field (Figure 2).

Table 1. Literature selection.

Categories	Criteria
General information	Year of publication Authors (citation frequency) Source impact and relevance to the research field Country
Research	Approach (Basic/Applied) Scope (Global/Local) Topic/Issue Question(s) Data/Methods Outcomes Knowledge gaps/Open questions
Disciplinary domain	Disciplines Psychology and Neuroscience, Medicine and Biology, Architectural Engineering Design and Urban Planning, Environmental Science, Social Science and Humanities, Engineering and Computer Science, Politics and Economics Subject area Health and Wellbeing, Society, Environment, Economics
Biophilic Metrics	Qualitative Research Multidimensional effects on urban livability Quantitative Research Rating systems, Indicators, Parameters, Measurements Applied Research Scale: Biophilic Design, Biophilic Urbanism Design metrics: Dimensions, Elements, Attributes, Tools, Patterns

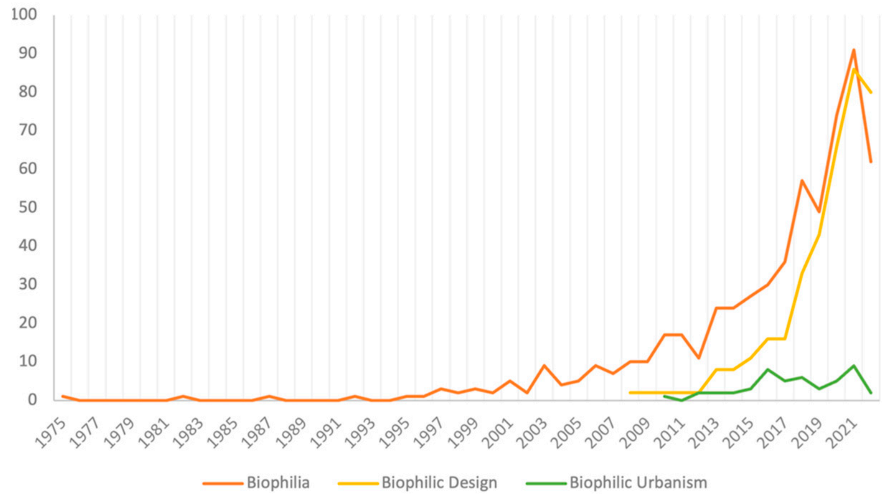

Figure 2. Timing and quantity of biophilic-related keywords occurring in publications.

2.2. Theoretical-Analytical Framework

An in-depth analysis was carried out in two phases to provide a comprehensive framework of Biophilia in theory and practice. While interconnected in their development, these two aspects were processed in parallel sections. As to the state of the art, we synthesized the evolution of the Biophilia concept by matching theories and definitions varying over time. Then, we conducted an analytical review built on quality, quantity, and application. The 3-metric approach helps to understand how Biophilia shapes the built environment based on human–nature interactions. Each metric is presented individually:

- Qualifying: Assuming biophilic effects as a variety of benefits to humans and urban livability offered by Biophilia, a two-step qualitative analysis was developed: Step 1: Literary resources were sorted by seven disciplinary domains (Psychology and Neuroscience/P&N, Medicine and Biology/M&B, Architectural Engineering Design and Urban Planning/D&P, Environmental Science/ES, Social Science and Humanities/SSH, Engineering and Computer Science/ECS, Politics and Economics/P&E); four sectors (Health and Well-being/HW, Society/SOC, Environment/ENV, Economics/ECO); and two research approaches (Basic Research/BR, Applied Research/AR), even including quantitative indicators or Metrics (M). Step 2: Effects of Biophilia, BD, and BU were identified under the abovementioned four sectors (HW, SOC, ENV, ECO); six dimensions (Physical, Cognitive–Mental, Affective–Emotional, Socio-Relational, Ecological–Environmental, Economic–Financial); and three types of human experiences of nature (Direct, Indirect, Space and Place) proposed by Kellert and Calabrese [19].
- Quantifying: The analysis was performed by presenting both key measuring tools adopted by evidence-based research and rating systems tested in BD and BU applications. They were ordered by grouped sectors (HW, ENV, SOC-ECO).
- Upscaling: Biophilia application was examined through a cross-scale approach by exploring design principles, instruments, and practices used in BD and BU.

3. Biophilia Concept

In addressing RQ1, we present the concept of Biophilia as a result of diverse disciplinary perspectives. Through 38 definitions (Table 2), we trace its evolution from the initial hypothesis to grounded theory and practical applications. Finally, we conclude the section with our conceptualization.

Table 2. Chronological selection of Biophilia-related definitions and their conceptual evolution.

Year	Reference	Concept	Definition
1964	[13]	Biophilous Orientation	"the tendency to preserve life and to fight against death is the most elementary form" (p. 45)
1973	[31]	Biophilia	"the passionate love of life and of all that is alive; it is the wish to further growth, whether in a person, a plant, an idea, or a social group" (p. 366)
1979	[32]	Biophilia	"the human bond with other species" (p. 43)
1984	[15]	Biophilia	"the innate tendency to focus on life and lifelike processes" (p. 1) "the urge to affiliate with other forms of life" (p. 85) "dependence on other organisms" (p. 118)
1993	[33]	Biophilia	"the innate emotional affiliation of human beings to other living organisms" (p. 31)
1993	[14]	Biophilia Hypothesis (BET)	"after humans migrated to the built environment, the evolutionary dependence on nature evolved into thinking about nature for survival and personal fulfillment" (p. 43)
1994	[34]	Biophilia	"the inborn affinity human beings have for other forms of life, according to circumstances, by pleasure, or a sense of security, or awe, or even fascination blended with revulsion" (p. 360)
2008	[35]	Biophilia/BET	"the inherent human inclination to affiliate with natural systems and processes, most particularly life and life-like features of the nonhuman environment" (p. 462)
2018	[36]	Biophilia	"mankind's innate biological connection with nature" (p. 43)
2008	[16]	Biophilic Design (BD)	"the deliberate attempt to translate an understanding of the inherent human affinity to affiliate with natural systems and processes—known as biophilia—into the design of the built environment" (p. 13)
2008	[18]	BD	"a new language for interpreting the built environment" (p. 347) "biophilia represents an abundantly creative moment in design" (p. 349)
2015	[19]	BD	"is to address these deficiencies of contemporary building and landscape practice by establishing a new framework for the satisfying experience of nature in the built environment" (p. 6)
2018	[17]	BD	"creating a good habitat for people as a biological organism (animal), in the modern cities and built environment" (p. 12)
2018	[36]	BD	"the process of basing decisions about the built environment on intuition or credible research—derived from either an appetency for nature or measurable biological responses, respectively—to achieve the best possible health outcomes." (p. 44)
2018	[37]	BD	"the emerging practice of designing [. . .] buildings that incorporate important elements of nature" (p. 276)
2009	[38]	Biophilic Urbanism (BU)	"a creative mix of green urban design with a commitment to outdoor life and the protection and restoration of green infrastructure from the bioregional to the neighborhood level" (p. 227)
2011	[21]	Biophilic Cities	"Cities that put nature first in its design, planning, and management, they recognize the essential need for daily human contact with nature as well as the many environmental and economic values provided by nature and natural systems. [. . .] A biophilic city is even more than simply a biodiverse city: It is a place that learns from nature and emulates natural systems, incorporates natural forms and images into its buildings and cityscapes, and designs and plans with nature" (pp. 45–46)

Table 2. *Cont.*

Year	Reference	Concept	Definition
2016	[39]	Biophilic Cities	"1. Biophilic cities are cities of abundant nature and natural experiences. 2. Biophilic cities are biodiverse cities—places with rich flora, fauna, fungi. 3. Biophilic cities are multisensory cities. 4. Biophilic cities are cities of interconnected, integrated natural spaces and features. 5. Biophilic cities immerse us in and surround us with nature; in biophilic cities one does not visit nature, one lives in nature. 6. Biophilic cities are outdoor cities. 7. Biophilic cities embrace the blue as well as the green; the marine and aquatic as well as the terrestrial. 8. Biophilic cities celebrate the small and large; the microscopic to the celestial. 9. Biophilic cities are cities where citizens care about and are engaged with nature; residents of all ages are actively involved in enjoying, watching, learning about, and participating in the nature around them. 10. Biophilic cities foster a profound curiosity; they are cities of awe. 11. Biophilic cities care about and nurture other forms of life; they are cities that value inherent worth and the right for other species to exist. 12. Biophilic cities care about nature beyond their borders. 13. Biophilic cities invest in nature. 14. Biophilic cities are inspired by and mimic nature. 15. Biophilic cities exhibit and celebrate the shapes and forms of nature. 16. Biophilic cities seek an equitable distribution of nature and natural experiences" (p. 25)
2020	[40]	Biophilic Cities	"Cities that contain abundant nature (trees, greenery, animals, gardens) and opportunities to connect with and experience this nature" (p. 280)
2020	[41]	Biophilic Cities Network	A global movement of individuals, organizations and partner cities that have signed the Biophilic Cities pledge and agree to work on behalf of more natural cities and urban environments" (p. 284)

The term "Biophilia" comes from the Greek words "bio" (βίος, "life, alive") and "philia" (φιλία, "love, amity, attachment"); thus, it means "love for life". Biophilia finds its roots as far back as the 4th century BC, when Aristotle introduced the notion of "philia" as an interspecies relationship, extending its connotation to reciprocity that underpins social, political, and moral values [42]. However, the term itself was coined by socio-psychologist Fromm in 1964 to highlight the human tendency to preserve every living being, in contrast to notions of "biophobia" (inherited fear of nature and animals) or "necrophilia" (fascination for death) [13]. Even then, he linked this passionate love of life to individual and societal fulfillment across species [31]. The concept of Biophilia was popularized by Crafoord Prize-winning biologist Wilson in the homonymous book as an innate emotional affiliation of humans to nature and other species or lifelike processes [32]. Drawing on Evolutionary Biology, he assumed that it is rooted in our genetic attitude to live in direct contact with nature [15]. This inborn attraction to natural settings and alive organisms, with their beauty and complexity, affects our skills and emotions: as a biological vector, it guides human evolution; additionally, it evokes a sense of pleasure or awe, akin to the sublime [33]. The man–nature interrelation has historically driven humanity in search of the right place to live, even considering both safety and aesthetics [34]. Joined by social ecologist Kellert, Wilson gathered anecdotal and evidence-based research on biophilic effects from diverse scientific areas to turn his intuition into a ground theory, known as the Biophilia Hypothesis (BET) [14]. They argued that our primitive dependence on nature was retained over time and adapted to artificial habitats, forging unedited connections with them to ensure survival and foster identity [35]. In an effort to establish a novel research field, they substantiated the mutual advantages of Biophilia for people and the environment [14]. Fifteen years later, Kellert took BET to the next step of development. He translated it into real-world scenarios by coining the term Biophilic Design (BD) to best describe our evolving relationship with the natural world [16]. BD represents a groundbreaking approach to architectural thinking: it aims to provide a fulfilling human–nature experience even indoors by merging Engineering and Landscape Design to bridge the gaps in contemporary building practices [17–20]. Beyond green and sustainable architecture, BD is an evidence-based process that uses nature to convert a building into a living organism interacting with the occupants, thereby enhancing their livability and environmental performances [18,19,36,37]. Next, urban planner Beatley introduced Biophilic Urbanism (BU) to shift in scale and extend the BET to cities, metropolises, and bioregions. His works offer several concepts within the realm of BU. He first associated BU with a creative mix of urban design and commitment to protecting outdoor life across multiple scales, applying a "room to region" approach [38]. Subsequently, he defined Biophilic Cities as a place where living beings, natural shapes, and systems are perfectly incorporated into buildings and cityscapes, thus prioritizing the need for daily contact with nature in urban design and planning [21]. Finally, he added 16 definitions of Biophilic Cities to emphasize their health-enhancing potential, ecological benefits to experience and safeguard urban biodiversity, and the social role of nature in favoring people-to-people exchanges [39]. BU carries the global imperative to redefine urbanity [40]. With this goal in mind, Beatley established the Biophilic Cities Network, a platform involving individuals, organizations, and cities worldwide to include Biophilia in urban policies and practices [41]. Today, Biophilia is also expressed in forms of activism: Söderlund shed light on biophilic social movements, whose supports strive to change urban planning by sharing actions and desires to create healthier and more pleasing cities [24]. Krčmářová draws a connection between present-day expressions of Biophilia and its very origin: BET issued by Wilson and his successors appears to have been influenced by analogous bottom-up initiatives, notably the American environmental movements that emerged in the 19th and 20th centuries to promote a harmonious relationship between man and the natural environment [43]. Amidst a multitude of notions and applications, we noticed the lack of definitions of Biophilia that emphasize its benefits. This is because we propose an extended concept bringing together beneficiaries, relations, means, and context. Hence, we define Biophilia as a "beneficial experience of interacting with nature—in all its forms—through senses and emotions, whose positive effects are mutually increasing in the built environment when designed according to Biophilic Design and Biophilic Urbanism." This benefit-oriented notion spotlights both the purpose of this paper and its analytical approach.

4. Biophilic Metrics

4.1. Qualifying

Human exposure to nature exerts positive or negative impacts on individuals and the community. As much of the literature demonstrates, these two aspects (Biophilia and biophobia) have often been postulated as the mutual emotional responsiveness of humans who experience nature [14].

Referring to RQ1, we look at just the advantages of Biophilia in improving urban livability—biophilic effects—because they outweigh the disadvantages to date, as proven by the previous literature review papers [44–46]. Biophilic effects result from the interaction between humans and nature that occurs through contact (direct/indirect, real/virtual) or exposure to environments incorporating nature and its derivates via BD and BU (hereinafter mentioned as biophilic settings or biophilic habitats). Through the two-step qualitative analysis, we examined biophilic effects as outcomes originating from Basic Research (BR) and Applied Research (AR). These approaches support the scientific basis of Biophilia in a complementary way: BR relies on empirical research; AR employs evidence-based studies implemented via questionnaires, online surveys, case studies, observational studies, comparative studies, and forecast scenarios. The first analytical step showed how scientific interest in Biophilia varies by discipline, sector/dimension, and research approach (Table 3). Considering the multidisciplinary nature of most of the items, as depicted in Figure 3, Biophilia was mainly investigated in Architectural Engineering Design and Urban Planning

(52), Psychology and Neuroscience (29), Environmental Science (23), and Medicine and Biology (16). Comparatively, it appeared less frequently in Social Science and Humanities (11), Politics and Economics (7), and Engineering and Computer Science (4). From a sectoral perspective, 53% of studies draw attention to the Health and Well-being benefits of Biophilia, followed by Environmental consideration (29%), and equally by Social (9%) and Economic effects (9%). Furthermore, a country-based review was conducted, considering the first affiliation and the funding source in cases of multi-authorship (Figure 4). A substantial portion of Biophilia research originates from the USA and Australia (46%); this underscores the geographical nexus between the concept's origin, dissemination, and investment. Developed economies are the prominent investors in the research field. The second step (Table 4) identified 23 categories of biophilic effects sorted by direct or indirect people–nature interactions and experiences in space and place. We qualitatively examined biophilic effects on humans (HW), society (SOC), the environment (ENV), and economics (ECO), substantiated by scientific evidence from the reviewed items. Items were clustered based on the prevalent biophilic effect advocated. Because many demonstrated more than one benefit, their cross-references appear repeatedly. The following sections group biophilic effects by four sectors and six dimensions, stressing their reciprocity as an added value. Human–nature interaction offers advantages to people, living beings, and the environment; on the contrary, the natural surroundings also encourage more frequent and impactful exchanges.

Table 3. Basic and Applied Research supporting biophilic effects.

Year	Reference	Discipline	HW	SOC	ENV	ECO	BR	AR	M
1984	[15]	M&B	✓				✓		
1993	[14]	M&B/SSH	✔	✓			✓		
1999	[47]	M&B	✓				✓		
	[48]	P&N	✓				✓		
2000	[49]	P&N/SSH	✔	✓			✓		
2002	[50]	P&N/SSH	✔	✓			✓		
2003	[51]	P&N/SSH	✔	✓			✓		
2007	[52]	P&N	✓				✓		
2008	[16]	P&N/D&P	✔		✓		✓		✓
2009	[38]	D&P/SSH/P&N	✓	✔	✓		✓		✓
	[53]	M&B	✓					✓	
2010	[22]	D&P/P&E/ES			✓	✔	✓		
2011	[21]	D&P/SSH/P&N	✓	✔	✓		✓		✓
	[54]	P&N	✓					✓	✓
2012	[55]	SSH		✓				✓	
	[56]	SSH/D&P/ES		✔	✓		✓		
	[57]	P&E				✓		✓	✓
2013	[12]	D&P/SSH		✓	✔		✓		
	[58]	P&N/D&P	✔		✓		✓		
	[59]	P&E/D&P			✓	✔	✓		
	[60]	D&P/ES			✓		✓		
2014	[42]	P&N/SSH	✔	✓			✓		
	[61]	P&N/D&P	✔		✓		✓		✓
	[62]	P&N	✓					✓	
	[63]	D&P/ES			✓		✓		
2015	[19]	D&P/P&N/SSH	✔	✓	✓		✓		✓
	[64]	D&P/ES			✓			✓	
	[65]	P&N	✓				✓		
	[66]	P&N	✓					✓	
	[67]	P&N/SSH	✔	✓			✓		

Table 3. *Cont.*

Year	Reference	Discipline	HW	SOC	ENV	ECO	BR	AR	M
2016	[39]	D&P/P&E/P&N	✓		✓	✔	✓		✓
	[68]	P&N/D&P	✔		✓			✓	
	[69]	P&N	✓				✓		
	[70]	SSH/D&P/ES		✔	✓		✓		
	[71]	D&P/ES			✓		✓		
	[72]	D&P/P&N/SSH	✓	✓	✔		✓		
	[73]	D&P/ES			✓		✓		
	[74]	D&P/ES			✓		✓		
2017	[75]	SSH/P&N	✓	✔				✓	
	[76]	SSH/D&P/P&N	✓	✔	✓		✓		
	[77]	D&P/ES/P&E			✔	✓	✓		
	[78]	D&P/ES/P&E			✔	✓		✓	
2018	[17]	SSH/D&P/P&N	✔	✓	✓		✓		✓
	[79]	M&B/P&N	✓					✓	✓
	[80]	M&B	✓				✓		
	[81]	M&B	✓				✓		
	[82]	M&B/P&N	✓				✓		
	[83]	P&N	✓					✓	
	[84]	P&N	✓					✓	✓
	[85]	P&E				✓		✓	✓
2019	[20]	P&N/D&P	✔		✓		✓		✓
	[86]	M&B/D&P	✔		✓		✓		✓
	[87]	M&B	✓				✓		
	[88]	M&B	✓				✓		
	[89]	M&B/P&N	✓				✓		
	[90]	P&N/D&P	✔		✓		✓		✓
	[91]	D&P			✓			✓	
	[92]	D&P/ES/SSH	✓		✔		✓		
	[93]	D&P			✓		✓		
	[94]	D&P			✓		✓		
	[95]	P&E/D&P			✓	✔		✓	
	[96]	P&E				✓		✓	✓
2020	[7]	P&N/D&P	✔		✓		✓		
	[97]	ECS	✓				✓		
	[98]	P&N/D&P	✔		✓		✓		
	[99]	P&N/SSH/ECS	✔	✓			✓		✓
	[100]	SSH/D&P		✔	✓		✓		
	[101]	SSH		✓				✓	
	[102]	D&P/P&E			✔	✓		✓	✓
	[103]	D&P/ES			✓			✓	
2021	[1]	D&P/ES			✓		✓		
	[23]	D&P/ES			✓		✓		✓
	[25]	D&P/P&N	✓		✔		✓		
	[45]	M&B/P&N	✓					✓	
	[104]	M&B/ECS	✓					✓	✓
	[105]	M&B/ECS	✓					✓	
	[106]	P&N/D&P	✔		✓		✓		
	[107]	D&P/ES	✔		✓		✓		✓
	[108]	P&N	✓					✓	
	[109]	P&N	✓					✓	✓
	[110]	P&N/D&P	✔		✓			✓	
	[111]	D&P/ES			✓		✓		
	[112]	D&P/ES			✓		✓		✓
	[113]	D&P/ES			✓		✓		
	[114]	P&E/SSH/D&P		✓	✓	✔		✓	

Table 3. *Cont.*

Year	Reference	Discipline	HW	SOC	ENV	ECO	BR	AR	M
2022	[46]	D&P/ES/P&N	✓		✔		✓		✓
	[115]	M&B	✓					✓	
	[116]	P&N	✓					✓	✓
	[117]	M&B	✓					✓	
	[118]	P&N/D&P	✔		✓			✓	
	[119]	P&N/D&P	✔		✓			✓	
	[120]	P&N/D&P	✔		✓			✓	
	[121]	D&P/ES			✓			✓	
	[122]	D&P/P&N	✓		✔		✓		
	[123]	D&P/ES			✓			✓	✓
	[124]	D&P			✓			✓	✓
	[125]	P&E				✓		✓	✓

Biophilic effects are sorted by discipline (Psychology and Neuroscience/P&N, Medicine and Biology/M&B, Architectural Engineering Design and Urban Planning/D&P, Environmental Science/ES, Social Science and Humanities/SSH, Engineering and Computer Science/ECS, Politics and Economics/P&E); sector/dimension (Health and Wellbeing/HW, Society/SOC, Environment/ENV, Economics/ECO); and research approach (Basic Research/BR, Applied or Evidence-based Research/AR), including quantitative tools or Metrics (M). In the case of multidisciplinary items, the bold checkmark indicates the predominant discipline.

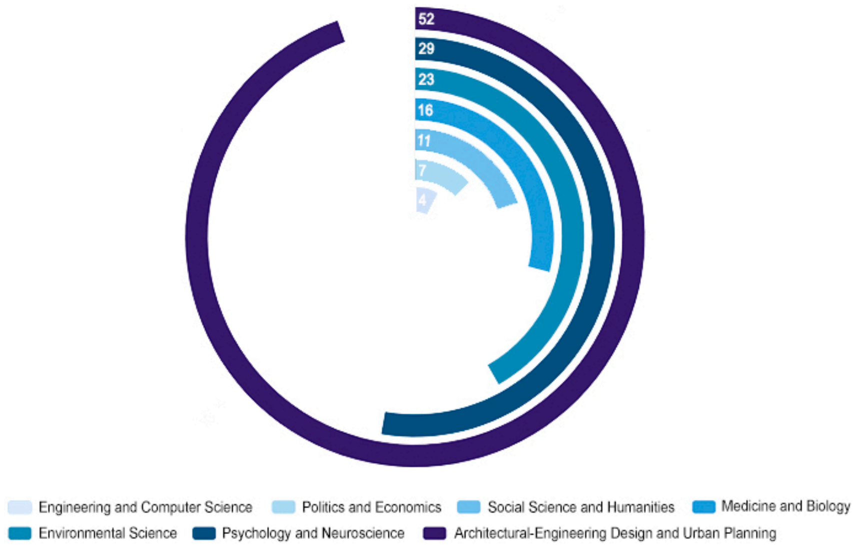

Figure 3. Items sorted by discipline (see Table 3).

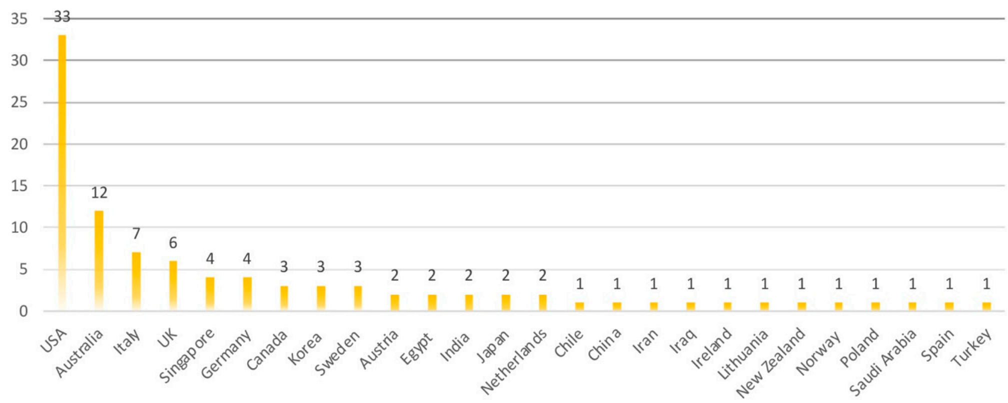

Figure 4. Items sorted by countries investigating Biophilia.

Table 4. Biophilic effects resulting from human–nature interaction in the built environment.

Sector/Dimension			Biophilic Effects	Direct Experience	Indirect Experience	Experience of Space and Place	Reference
HW	Physical		Motor function/way-finding/physical wellness	•	•	•	Derr & Lance [55]; O'Regan et al. [104]; Wilson [15]
			Bodily function regulation	•	•		Kahn [47]; Huntsman & Bulaj [115]; Yin et al. [79]
			Illness recovery/immune system support	•	•		Zare et al. [45]; Grinde & Patil [53]; Salingaros [86]; Totaforti [80]; El Messeidy [87]; Arvay [81]; Verzwyvelt et al. [105]
			Biorhythm control/longevity	•			Parsaee et al. [88]
HW	Psycho-logical	Cognitive–Mental	Mental health and recovery/stress reduction	•	•	•	Bolten & Barbiero [7]; Xue et al. [20]; Kahn & Kellert [50]; Ulrich [48]; Tsunetsugu et al. [52]; McDonald et al. [82]; Zhu et al. [117]; Marselle [89]; Schiebel et al. [116]; Gullone [49]
			Attention/memory/creativity	•	•		Emamjomeh et al. [97]; Mollazadeh & Zhu [106]
			Learning and adaptive skills/problem solving	•		•	Browning et al. [61]; Kavathekar & Bantanur [107]; Lei et al. [118]; Abdelaal [90]; Jones [58]; Peters & D'Penna [98]
			Motivation/satisfaction/self-confidence/ fulfillment	•			Aristizabal et al. [108]; Hähn et al. [109]
		Affective–Emotional	Emotional recovery/comfort and safety/rejuvenating potential	•	•		Berto et al. [83]; Meltzer et al. [84]; Gillis and Gatersleben [65]
			Positive mood/enjoyment/happiness	•	•		Capaldi et al. [62]; Hinds & Sparks [54]
			Preference/aesthetic pleasure/fascination	•	•		Sayuti et al. [110]; Boğa et al. [119]; Gochman [68]; Kellert et al. [16]; Berto et al. [69]; Khozaei et al. [120]; Chang et al. [99]; Kalvaitis & Monhardt [66]
			Spiritual and ethical values	•		•	Kellert & Wilson [14]; Santas [42]; Besthorn & Saleebey [51]
			Topophilia	•		•	Kellert [17]; Kellert & Calabrese [19]; Beery et al. [67]
SOC	Socio-Relational		Social interaction	•			Beatley [38]; Jaszczak et al. [100]
			Social cohesion/membership	•		•	Beatley [21]; Söderlund & Newman [75]
			Environmental awareness/resilient behaviors	•		•	Soga et al. [70]; Totaforti [101] Tidball [56]; Beatley [76]
ENV	Ecological–Environmental		IEQ/OEQ	•			Andreucci at al. [25]; McGee et al. [91]; Vileniske at al. [121]; Newman et al. [77]; Africa et al. [92]; Aye et al. [93]

Table 4. *Cont.*

Sector/Dimension		Biophilic Effects	Direct Experience	Indirect Experience	Experience of Space and Place	Reference
ENV	Ecological–Environmental	Energy/resource efficiency	•			Santiago Fink & Kaltenegger [71]; Lee & Park [122]; Nitu et al. [123]; Daniels et al. [102]
		Ecosystem services/biodiversity	•			Panlasigui et al. [1]; El-Baghdadi & Desha [78]; Revell & Anda [63] Kellert [72]; Birkeland [73] Ignatieva & Ahrné [60]; Carter & Henríquez [111]; Zari [94]
		Carbon neutrality/climate resilience/sustainability	•			Beatley & Newman [12]; Tarek & Ouf [23]; Zhong et al [46]; Reeve et al. [64]; Santiago Fink [74]; Cabanek et al. [103]; Lee & Kim [112]; Thomson & Newman [113]; Alaskary & Alrobaee [124]
ECO	Economic–Financial	Worker productivity/attraction	•		•	Wallmann-Sperlich [95]; Afify et al. [125]; Ayuso Sanchez et al. [85]
		Added value/cost-sa ing/carbon economy	•		•	Newman [22,59]; Xue et al. [96]; Browning et al. [57]
		New jobs	•		•	Beatley [39]; Novosadová & Knaap [114]

Items sorted by sector/dimension. The color distinction is related to the type of experience.

4.1.1. Physical Benefits (HW)

Salutogenic effects of Biophilia are well documented. We have identified four main classes of biophilic effects that improve physical features and performance.

- Motor function/wayfinding/physical wellness: According to Wilson's evolutionary theory, our current physical skills result from a long exposure to nature. This process contributed to the development of senses, motor functions, coordination, and balance. Moreover, sensory richness intensifies the nature-based experience through scents, colors, or daily/seasonal rhythms of life [15]. Engaging in physical activities in natural settings improves our wayfinding and favors harmonious growth. Conversely, proximity to parks, bike lanes, and pedestrian pathways incentivizes movement, boosting body performance while reducing Body Mass Index from childhood [55]. Whether real or virtual, street-level greenspaces enhance the physical health and wellness of residents. A recent study reported a 2.8% increase in self-reported health among people who digitally experienced urban nature [104].
- Bodily function regulation: Additional physiological responses triggered by connections with nature involve the function regulation of our tissues, organs, and systems. Randomized trials conducted in biophilic settings showed a significant reduction in physical distress by decreasing muscle tension, systolic and diastolic blood pressure, stress hormones (cortisol, DHEA level), skin conductance, and sympathetic nervous system activity [14,47]. Similar effects in regulating blood pressure, heart rate, and galvanic skin response were also detected after a 5-minute exposure to a biophilic virtual environment [79]. BD is regarded as a non-pharmacological approach for alleviating migraines or chronic nerve pain and improving sleep quality [115].
- Illness recovery/immune system support: Both direct and indirect contact with living forms have been found to accelerate clinical recovery from temporary or chronic diseases (cardiovascular, metabolic, gastrointestinal, and respiratory), even aiding in preventing physical disorders (obesity, vit. D deficiencies, attention deficit, and

hyperactivity) and aging processes [53]. After two centuries of evidence on the healing power of nature arguing the therapeutic value of the environment [86], recent studies unveiled the importance of applying BD to hospitals and sanitary facilities, where interaction with nature empowers patients and makes spaces healthier [45,80,87]. A pilot study proved the benefits of biophilic settings using Virtual Reality to ease physical pain in oncology patients undergoing chemotherapy [105]. Furthermore, exposure to nature strengthens the immune system, leading to a 40% acceleration in white blood cell production against infections and cancer [81].

– Biorhythm control/longevity: Medical research advocates for nature's support of biorhythm control and longevity. BD aids in meeting people's photobiological needs, especially in extreme climate conditions [88].

4.1.2. Cognitive–Mental Benefits (HW)

Against mental penalty due to urban alienation from nature, we established four categories of biophilic effects underlining how Biophilia enhances cognitive–mental health.

– Mental health and recovery/stress reduction: Modern urban lifestyles have led to an increase in stress, anxiety, suicides, schizophrenia, and depression, occurring more frequently than in rural regions. Exposure to natural features contributes to preventing and curing them [49]. Our innate tendency toward nature is linked not only to genetics but also to automatic mental processes, as proven by testing BET digitally [116]. Extensive research in Psychology and Neuroscience documented the multiple pathways by which natural stimuli favorably affect our cognitive and emotional development [50]. Traditionally, the field of Environmental Psychology provided substantial evidence demonstrating a spontaneous decrease in mental stress in the presence of nature [45]. Sensorial interaction with nature improves psychological states [48]. Even exposure to indirect representations of nature, such as natural analogs, visual reproductions, sounds, and materials, can lead to mental well-being [52]. Living in neighborhoods with a greater percentage of green spaces and flowering plant species improves mental health [82]. Similarly, urban horticulture and gardening are used to reduce symptoms of mental disorders, such as Autism, ADHD, Alzheimer's, Parkinson's, dementia, schizophrenia, and depression with higher benefits for women [53]. Moreover, there is wide evidence supporting nature's role in mental recovery: for instance, experiencing Biophilia through Virtual Reality can mitigate cognitive dysfunction in elderly patients undergoing laparoscopic surgery [117]. The design lesson learned during the pandemic has steered research to fresh perspectives on the healing power of nature. Through a daily nature dose, BD can counter the psychological short-term and long-term effects of COVID-19 [7,20]. Throughout the lockdown, governments have officially recognized urban green spaces as essential for physical and mental well-being [25]. In compliance with the latest urban orientations, Marselle [89] applied several methods of Environmental Psychology (Preference Matrix, Fractal Geometry, and Ecosystem Service Cascade Model) to prove the beneficial impact of Biophilia on mental well-being, thereby grounding the scientific foundation of BU as science applied in biodiversity and health research [64].

– Attention/memory/creativity: Attention Restoration Theory suggests that engaging with nature can facilitate the renewal of cognitive functions, encompassing attention, concentration, memory, reasoning, creativity, and imagination. The same theory also argues that urban life causes mental fatigue due to an excess of attention stimuli. However, Biophilia-oriented research has shown that spending time in nature refreshes brainpower [45]. Comparative tests conducted in both real and virtual biophilic habitats have confirmed an enhancement of short-term memory by up to 14%, along with an increase in attentive and imaginative ability [97,106]. Previous experiments have stressed the positive impact of indoor plants on self-reported alertness and the relaxation of attention, especially after overexposure to energy-intensive activities [53].

- Learning and adaptive skills/problem solving: Regular connections with nature can perfect learning skills and productivity. As per Wilson's theory, our emotions govern how we learn: research has evidenced that BD assists in learning through daylight, which accelerates the process by 26%; additionally, sunlight in the workplace raises the serotonin levels of occupants, boosting successful performance and lowering absenteeism due to sickness [61,107,118]. Experiencing the variety and complexity of nature through biomorphic patterns or fractal geometries stimulates logical thinking, problem solving, and risk assessment, similar to the effects of fight-or-flight responses in both children and adults, as proven by pioneering studies on Biophilia [50]. Beyond housing, hospitals, and offices, the final BD frontier focuses on educational facilities (schools, university campuses, and prisons) not only to test the biophilic restorative qualities through NBSs but also to foster an innovative bio-cultural approach to space [58,90,98].
- Motivation/satisfaction/self-confidence/fulfillment: Biophilia's genetic foundation predisposes individuals to experience motivation, personal fulfillment, and increased self-confidence. Empirical investigations conducted in biophilic settings have revealed a strong correlation between mental well-being and feelings of accomplishment among participants, leading to higher rates of satisfaction and self-confidence [108,109]. Finally, recent research has employed implicit test strategies to unveil our innate inclination to engage in and with nature as a mental reward to corroborate the psycho-evolutionary theory that underlies Biophilia [116].

4.1.3. Affective–Emotional Benefits (HW)

Biophilia relies on an emotional and sensory exchange with nature, positively impacting the human affective dimension. We identified five biophilic effects that validate this.

- Emotional recovery/comfort and safety/rejuvenating potential: Evidence from Behavioral Science and Emotional Psychology demonstrates that direct or indirect visual connections to nature result in a notable emotional recovery: even merely observing nature through a window or related images induces a sense of visual relaxation [53]. Likewise, the touch-sensory experiences in interiors constructed with natural materials (at least 45%) inspire comfort and safety [52]. The rejuvenating potential of Biophilia has also been confirmed by a psychological literature review, which has evidenced the dose–response relationship between human emotions and BD [65]. Biophilia activates our emotions in response to natural stimuli, both indoors and outdoors, as observed by studies involving individuals visiting parks with a high degree of naturalness or participants in outdoor orientation programs [83,84].
- Positive mood/enjoyment/happiness: Natural landscapes can differently influence our mood. Hinds and Sparks [54] highlighted how forests, mountains, seas, and extreme natural panoramas mostly evoke a sense of relaxation, awe, and freedom. Urban areas can also foster positive feelings: delight and tranquility were experienced in the presence of moving water, in backyard gardens, or in unexpected wild scenarios in urban parks [25]. A meta-analysis by Capaldi et al. [62] confirmed an analogous correlation between nature connectedness and happiness.
- Preference/aesthetic pleasure/fascination: Referring to Darwin's Preferred Habitat Theory, much research indicates an innate fondness for BD as it better satisfies the biological needs of humans. The recent surge in the biophilic industry has been linked to major users' preferences for furniture designed with natural forms, materials, and patterns [110,119]. Analogously, Khozaei et al. [120] found a correlation between the growing application of BD in public buildings (hospitality and recreation facilities, shopping malls) and the need to meet the preferences of a wider audience. Shifting to the city scale, a pilot study tested the allure of Biophilia from a pedestrian perspective: 76% of participants preferred to spend their lunchtime in biophilic settings, where the pleasure of breathing fresh air and experiencing nature outweighed the cost of distance [68]. Chang et al. [99] examined the emotional effects of Biophilia using social

media, evaluating the constant presence of nature in positive memories as an indicator of biophilic preference. Exploratory studies, built on Evolutionary Theory and Savannah Theory, argue for the aesthetic potential of nature to appeal to people at any age. This fascination with nature arises from organic patterns and natural attributes [16]. According to Berto et al. [69], the coexistence of natural and anthropogenic elements within the built environment further evokes attraction to mystery and complexity. As per the Prospect-Refuge Theory, BD fulfills the human predilection for open views and protected vantage points: observational research proved that children's love for nature originates from the countless possibilities for playing outdoors [66].

- Spiritual and ethical values: Biophilia positively influences spiritual and ethical well-being. A deep connection with nature infuses life with meaning and strengthens religious beliefs [14]. Furthermore, Biophilia promotes ethics by recognizing the freedom and dignity of all species, given their mutual interdependence in the biosphere [42,51].
- Topophilia: As an extension of BET, Kellert and Calabrese [19] introduced the Topophilia Hypothesis to broaden the emotional dimension of Biophilia from individuals to communities. Topophilia refers to human affiliation with nonhuman nature and attachment to special places. Environmental Psychology attributes such a meaningful "sense of place" to cultural or experiential learning. Therefore, the restorative power of nature is extended to anthropogenic landscapes: people are captivated by historical and artistic sites perceived as carriers of universally recognized cultural values [65]. Through BD and BU, this concept was explored to reconnect urban dwellers with the unique identity of a place formed over time, culture, and tradition, enhancing environmental awareness while respecting the genius loci [17,67].

4.1.4. Social Benefits (SOC)

The social dimension of Biophilia emerges when it is experienced collectively and fulfills community needs through the following three biophilic effects.

- Social interaction: Most nature-based activities foster social interaction [48]. Biophilic settings offer multiple opportunities to enjoy the benefits of nature connectedness within families or larger groups: leisure activities and outdoor sports promote personal and cultural exchanges, helping in achieving common goals [38]. Field research stressed that urban parks or green spaces are frequented more often, as people associate them with improved livability and sociability [100]. Observational investigations unveiled that biophilic indoors make inhabitants more sociable, as they develop a stronger desire for friendship than residents not surrounded by nature [82].
- Social cohesion/membership: BD and BU prioritize forms of social cohesion. Scientific evidence found a strong correlation between street-level greenery and perceived social cohesion within the neighborhood; correspondingly, lower rates of crime and recidivism were recorded within nature-rich environments [75]. Engaging in biophilic activities, such as nature clubs, tree planting, or urban camping, brings together individuals who share a fascination for nature, encouraging a sense of community belonging [21].
- Environmental awareness/resilient behaviors: Social and ecological values intertwine deeply in building urban resilience. Biophilic cities promote social justice by maximizing the urban natural capital and ensuring an equitable distribution of bio-based assets among citizens. Additionally, biophilic initiatives and citizen science programs raise awareness about urban nature and inspire resilient behaviors [76]. Growing research confirms that regular experiences in nature, coupled with proper know-how, support sustainable attitudes and nurture ecological consciousness [55]. Assuming children as more receptive, a study demonstrated their engagement in environmental cleaning and biodiversity conservation after vicarious nature experiences [70]. Another study approached BU from an Urban Sociology perspective, demonstrating how human–nature interaction experienced in biophilic settings motivates individuals to become

environmental stewards of places over time [101]. Drawing on Community-Based Ecological Restoration and Social–Ecological Disaster Resilience, Tibdall [56] explored the potential of BU to enhance urban resilience across scales, thus empowering human roles within interdependent ecosystems.

4.1.5. Environmental Benefits (ENV)

Research in Architecture, Engineering, and Design Technology has established a scientific baseline for the environmental benefits provided by Biophilia through BD and BU. We have categorized such advantages into four distinct biophilic effects.

- Indoor Environmental Quality (IEQ)/Outdoor Environmental Quality (OEQ): Nature significantly improves IEQ and OEQ via passive, low-impact, and sustainable systems. BD and BU integrate NBSs in both indoor and outdoor spaces, aiming to maximize their socio-ecological effects [91]. According to Vileniske et al. [121], BD incorporates nature into living technologies, including isolated spots (indoor plants), vertical frontiers (green façade and walls, vertical farms), horizontal surfaces (green roof), and various natural elements (materials, shapes, colors, etc.). Through potted plants or green walls, BD was scientifically recognized for its ability to increase relative humidity, regulate temperatures, and reduce volatile organic compounds [82]. Green roofs are the most commonly used NBS for rainwater absorption; they can achieve retention rates of 70%, effectively alleviating the strain on urban sewer systems [77]. Besides reducing stormwater runoff, they offer multiple opportunities for reusing gray water and recycling excess drainage water [25]. Globally, roof gardens are widely used to renew urban policies through BU. Inspired by Singapore, an increasing number of cities are adopting its "green floor plate ratio," which mandates replacing the building floor space with an equivalent or double amount of vegetation [59]. Vertical greenery has evolved from green façades (covered by creeping plants rooted at the base of the building or in elevated planters) to green walls (bio-walls or vertical gardens), where plants are held in containers or hydroponic panels attached to a supporting structure. With support from Environmental Engineering, BD mainly employs green walls due to their effectiveness in enhancing air quality and the urban microclimate [91]. Utilizing plant roots and soil microbes as biofilters, green walls can reduce up to 60% of CO2 and 40% of other airborne pollutants [71]. BU encompasses a wide range of biophilic systems resulting from the implementation of BD across urban scales: buildings (roof gardens, green walls, vertical farms, and atria); neighborhoods (courtyards, parks, squares, street trees, and sidewalk gardens); and city/bioregions (urban forest, community gardens, blue-green infrastructure, ecological networks, and regional greenspace) [21]. All of these systems ensure a better urban microclimate and mitigate the heat island effect by 5 to 6 °C [92]. The simultaneous presence of diverse natural elements (greenery and water) and species optimizes the environmental impact of BU at different times: the tree canopy provides greater cooling effects during the daytime, while shrubs and grass tend to have a more pronounced cooling effect overnight [71]. BU leverages plants to naturally purify air, soil, and water through a combination of photosynthesis, evapotranspiration, and phytoremediation [91]. By merging various NBSs, BU helps reduce greenhouse gases, tackle aerodynamic issues for wind comfort, and favor natural ventilation, even offering inherent protection against air currents and noise generated by traffic congestion [25]. Structural Engineering studies have validated BD and BU using a mathematical approach to vet structural stability and equipment efficiency while ensuring user safety [93].
- Energy/resource efficiency: The building industry is deemed a major contributor to resource use and the associated carbon emissions. BD promotes high-performance architecture and low power consumption by means of greenery, daylight, and natural ventilation [122]. Bio-walls and green roofs insulate the building envelope, protecting it from direct solar radiation in the summer and preventing heat loss in the winter; this results in significant energy savings for both mechanical heating and cooling [92].

The thermal performance of a building is influenced by the plant species that cover or surround it: deciduous plants serve as a shading device in the summertime and let in the sunlight during wintertime, reducing energy consumption in both seasons; broad-leaved species reflect, transmit, and scatter light internally, minimizing electrical lighting demand by 33%. Simulating retrofit scenarios that use different species, Nitu et al. [123] showed how daylight joined with natural ventilation optimizes indoor thermal control. Drawing lessons from nature's efficiency, BD applies the science of biomimicry to develop novel passive heating and cooling systems. Dielectric elastomers integrated into homeostatic façades respond to sunlight by contracting and expanding to provide shading for the building. This innovation reduces mechanical system costs by up to 35% and preserves up to 50% of cooling energy by replicating convective motion. As for BU, biophilic cities exhibit the lowest energy consumption for managing storm drain sewage plants and air handlers compared to other cities [71]. BU promotes the optimal use of local resources through careful selection of sites and plant species that are better suited than others for specific purification processes and thermal conditions. Native vegetation thrives in the warmest or coldest regions, providing natural cooling/heating both indoors and outdoors. Similarly, it proves effective in water-scarce regions, functioning as a system for water harvesting through condensation and gray water recycling [39]. In the current challenge of resource efficiency, biophilic cities excel in enhancing urban metabolism [102].

– Ecosystem services/biodiversity: Beyond connecting people, nature, and structures, BU establishes ecological networks that include the fundamental ecosystem services of regulation, support, provisioning, and culture. Acknowledging these functions within the realm of Biophilia, el-Baghdadi and Desha [78] introduced the concept of "biophilic services" as an extension of ecosystem theories through the lens of Biophilia. Such services overcome the conventional "triple-bottom-line" of sustainability, promoting a "Penta-Matrix Approach" that lies on the five core values of Biophilic Thinking: environment, society, economics, technology, and aesthetics [63]. The large-scale approach of BU does not merely consider peri-urban areas and bioregions as territorial or socioeconomic resources, but it recognizes their pivotal ecological function within city management repair systems. This is why many cities are complementing their sustainable plans with biophilic targets and codes [77]. Given the global ecological crisis, integrating nature into urban design and planning becomes imperative for biophilic-thinking cities [72]. BU has the potential to constitute urban biomes acting as biodiversity incubators that preserve natural variety to enhance urban livability for both citizens and wildlife [73]. Cities around the world are experiencing repopulation or colonization of plant and bird species through biophilic urban systems, namely, via roof gardens, bio-walls, and blue-green infrastructure [77]. Nevertheless, the most promising results are observed in high-density cities, where a wide range of biophilic structures build habitats akin to forests for biological diversity [59]. Furthermore, BU delivers innovative tools to supplement existing biodiversity planning, such as "biodiversinesque", a novel landscape architecture mixing ecology and gardening to be implemented at both city or smaller biotope levels [1,60]. Through urban agriculture, and beekeeping, BU supplies secure food, especially in developing countries [111]. From a Citizen Science perspective, BU employs human sensory interaction to boost ecological functions, as citizens' perception is capable of detecting changes in the cityscape over time and seasons [94].
– Carbon neutrality/climate resilience/sustainability: Research strongly advocates for the role of Biophilia in addressing environmental stewardship in climate action [74]. BD and BU aid cities in paving the way to carbon neutrality by means of various strategies: low-energy buildings, NBSs as adaptation and mitigation measures to counteract the effects of climate change, greener and denser urbanization as a cost-effective model, carbon sequestration by plants, permaculture rooted in local production and native food species, and specific equipment for waste recycling and energy storage,

including solar farms [103,112]. BU unifies and complements traditional paradigms of resource-efficient and ecological cities. Thus, it contributes to urban renewal through a holistic approach aimed at building climate-proof cities able to implement responsive as well as strategic greening [64,113,124]. BU strives to achieve healthier cities and sustainable communities by adopting smart and resilient solutions [23,46]. BU incorporates nature into cities to reduce vulnerability, minimize damage, and prevent loss of life. Thereby, Biophilia enhances adaptive capacities for safe individuals and an inclusive society. BU makes cities inherently resilient and sustainable [12].

4.1.6. Economic Benefits (ECO)

The socio-psychological and environmental advantages described above were translated into economic benefits by assigning a monetary value to biophilic effects resulting from people–nature interaction. Both direct (productivity, added value) and indirect (cost-saving, new jobs) benefits were calculated to show how Biophilia can enhance industry and business revenue. They were grouped into three categories:

- Worker productivity/attraction: The majority of research aimed at harnessing biophilic effects focused on workplaces. A cost–benefit analysis proved that BD inspires changes and more active conduct, thus increasing workers' productivity [95]. Higher work performances have been registered within offices integrating multiple elements of BD, such as multisensory connection with natural systems, dynamic and diffused lighting, biomorphic patterns, and spatial layouts evoking a sense of refuge and mystery [125]. This high-performance potential of BD was also quantified through greenery and daylight, resulting in a significantly positive impact on workload and results [85]. Evaluating case studies of biophilic office spaces across the US, Browning et al. [57] estimated that annual productivity benefits averaged USD 2000 per employee working in daylighting schemes and USD 2999 per employee overlooking nature, associated with 15% fewer unproductive costs stemming from absenteeism. Biophilia is revolutionizing recruitment processes: among the companies investing in BD, organizations are allocating up to 80% of their strategy budget to attract top candidates and optimize productivity within more appealing ambiances.
- Added value/cost-saving/carbon economy: BD adds value to the traditional real estate market, as people are willing to pay up to 127% more for good views, proximity to parks, and waterfronts. There was an increase in properties including skylights (40%) and green street frontage (25%). Economic gains linked to biophilic settings arise from extended building lifespans, reduced water management expenses, and lower energy costs; notably, an annual energy cost saving of USD 2.5 million was estimated for banks, offices, or stores applying BD [57]. Another indirect profit pertains to reduced healthcare costs. In England, the psychophysical advantages of urban greenspaces were evaluated to reduce treatment costs by USD 2.1 billion [82]. Extensive research across 5795 hospitals in the US found that USD 93 million could be saved annually in healing costs through faster recovery and shorter hospitalization, jointly. Moreover, medication savings were associated with biophilic activities outdoors: USD 228 million in ADHD medication and USD 2200 per person in obesity treatments. Due to a lower rate of crime, aggression, and domestic violence registered in biophilic neighborhoods, New York and Chicago saved up to USD 1.7 billion and USD 162,200 in social costs, respectively [57]. In line with the Low Carbon Economy approach, BU offers the economic benefit of capitalizing trees for carbon capture and storage. Among biophilic cities, Singapore is a leader in the green market thanks to its Green Plan, which leverages greenery to lure investments, drive economic growth, and enhance urban livability [22,59]. Despite encouraging data, scarce financing in BU hinders its application and success. In this regard, Xue et al. [96] outlined that increased awareness of biophilic economics can motivate stakeholders to invest in evidence-based BD and BU.

– New jobs: Biophilia contributes to city finances via ecotourism, urban farming, outdoor sports, and public events, which generate economic value and create new job opportunities [39]. Specifically, the biophilic agent plays a novel and complementary role in urban development by fostering community projects and administrative programs aimed at implementing BU. Research conducted in Philadelphia assigned a socio-economic value of USD 8.6 million to these activities, factoring in working hours and financial support [114].

4.2. Quantifying

In response to RQ2, we identified 19 studies that sought to quantify the impact of Biophilia on human well-being and urban livability through different measurement tools. We classified items based on purpose, tool types, and rating scale, and we grouped them by sectors as well (Table 5). Within this framework, we differentiated between metrics based on biophilic principles to evaluate human–nature interaction (Ad hoc Tools) and metrics using techniques from other scientific fields to assess biophilic effects on the citizens, environment, and economy resulting from the application of BD and BU (Derived Tools). To give a comprehensive overview of biophilic measurement tools, we selected the most commonly used tools to date. They are examined in the two main groups, as follows:

– Ad hoc Tools: This group includes four indicators dealing with Biophilia related to individuals, BD, and BU. The Kellert–Shorb Biophilic Values Indicator (KSBVI) assesses the degree of Biophilia using nine psycho-behavioral responses (aesthetic, dominionistic, humanistic, moralistic, naturalistic, negativistic, scientific, symbolic, and utilitarian). Designed to evaluate an individual's experience in or with nature at a specific time, it is also capable of monitoring changes in biophilic attitudes over time through pre–post formats. The KSBVI consists of 99 statements and 11 items per biophilic value to be rated by a 4-point Likert scale [50,84]. The Biophilic Healing Index was developed by Salingaros [86] to evaluate the healing potential of BD, using a predictive model, which incorporates 10 Biophilic Design criteria (light, color, gravity, fractals, curves, detail, water, life, representations of nature, and organized complexity) and translates them into a numerical value ranging from 0 to 20. Beatley [21] provided Biophilic City Dimension and Indicators for turning any city into a biophilic city by meeting four categories (conditions/infrastructure, activities, attitudes/knowledge, and institutions/governance), along with 22 indicators to attain the minimum standards of BU. Recently, Alaskary and Alrobaee [124] introduced extra Biophilic Planning Indicators consisting of 11 descriptive and quantitative parameters intended to guide future actions at the neighborhood scale; they also included Simpson's Diversity Index to detect biodiversity.
– Derived Tools: The second group includes 15 measuring tools that vary by discipline, sector, and the object being tested. To estimate physiological and cognitive enhancements, Yin et al. [79] first assessed physical stress using three wearable biomonitoring sensors for heart rate (HR), skin conductance level (SCL), and blood pressure (BP), referring to a normal range scale; secondly, they evaluated attention and memory through Stroop tests and visual backward digit span tests. O'Regan et al. [104] gauged the effects of biophilic street design on physical health by correlating health descriptive statistics and self-reported health rates with greenspace exposure. In a preliminary attempt to review biophilic metrics, Kavathekar and Bantanur [107] mixed Braincheck tests and proxies for productivity to monitor occupants' performance in biophilic workspaces. This aligns with the majority of research adopting a psychometric approach to measure the psychological and emotional response to biophilic experiences by employing standard cognitive tests: Dot Probe Task (DPT), Implicit Association Test (IAT), and Approach Avoidance Task (AAT) to prove selective attention and preferences [116]; a self-assessment questionnaire to record affect-based experiential states [54]; Visual Working Memory (VWM), Sympathetic Activity Index (SAI), and Parasympathetic Activity Index (PAI) to test feelings and stress levels [90]; Building

Use Studies (BUS) and Office Productivity Network (OPN) surveys to assess perceived well-being and occupant satisfaction [109]; and lastly, online detection coupled with data analytics to quantify aesthetic pleasure and life satisfaction arising from human–nature connection [99]. To quantify the environmental effects of Biophilia, researchers considered resource efficiency and energy savings as performance measurement tools for BD and BU. For instance, Nitu et al. [123] assessed IEQ by environmental indicators (visual and thermal comfort, energy reduction) in biophilic retrofitting models. They refer to standard metrics from Building Physics such as Window-to-Wall Ratio (WWR), Daylight Factor (DF), U-Value, R-Value, Room Temperature (RT), electric lighting, and heating energy. Supplementary quantitative evaluation tools were linked to BD using both percentage and dimensional standards by Building Certification Systems: WELL, BREEAM, and LEED included Biophilia as a specific credit to be earned in each green rating system [46]. Daniels et al. [102] calculated the net community benefits of BU by matching the Millennium Ecosystem Assessment (MEA) and the Total Economic Value (TEV) framework. This approach allowed for measuring social effects and resource efficiency simultaneously. A selection of BD and BU solutions was also examined by applying a Benefit–Cost Ratio (BCR). According to urban stakeholders, the most cost-effective strategies included biophilic infrastructure, sensorial design, and green space place making [20]. Ayuso-Sanchez et al. [85] deployed the NASA Task Load Index to estimate workload among subjects within biophilic settings. Based on a seven-point scale, they found reduced fatigue perception and increased productivity, which could be quantified monetarily. Similarly, another study implemented self-assessment questionnaires with a three-point numerical scale to establish productivity ratings in diverse biophilic work settings [125]. All the above-mentioned studies share standard rating scales such as the Numerical Rating Scale (NRS), Cantril Ladder scale, Likert scale, and Positive and Negative Affect Schedule (PANAS).

Table 5. Measuring tools employed to quantify biophilic effects.

	Purpose	Ad Hoc Tools	Derived Tools	Rating Scale	Reference
HW	Human–nature interaction	KSBVI		4-point Likert scale	[84]
	Bodily functional response		HR/SCL/BP	Normal range/NRS	[79]
	Public health	Biophilic Healing Index		20-point NRS	[86]
	Self-reported health		Heath descriptive statistics/self-reported health rates	Quartile rank	[104]
	Attention/Memory		Stroop test/Backward digit span test	5-point NRS	[79]
	Improved task performance		Braincheck tests	Likert scale	[107]
	Selective attention/Preferences		DPT/IAT/AAT	10-point NRS	[116]
	Experiential feeling states		Self-Assessment questionnaire	5-point Likert scale	[54]
	Mood/Stress levels		VWM/SAI/PAI	PANAS	[90]
	Perceived well-being/satisfaction		BUS/OPN	3-point Likert scale	[109]
	Aesthetic pleasure/Life satisfaction		Online detection/Data analytics	10-point Cantril scale	[99]
ENV	Energy/Resource efficiency		WWR/DF/RT	Specific units	[123]
	BD performance		WELL/BREEAM/LEED	Percentage/Units	[46]
	BU standards	Biophilic City Dimension/Indicators		Percentage/Units	[21]
	BU standards	Biophilic planning indicators		Percentage/Units	[124]

Table 5. *Cont.*

	Purpose	Ad Hoc Tools	Derived Tools	Rating Scale	Reference
SOC—ECO	Worker productivity		Self-Assessment questionnaire	3-point NRS	[125]
	Workload perception/productivity		NASA-Task Load Index	7-point NRS	[85]
	Net community benefits		MEA/TEV	BCR scale	[102]
	Socioeconomic benefits		BCR	BCR scale	[20]

4.3. Upscaling

As for RQ3, BD and BU offer tangible and daily biophilic experiences within the built environment, across scales. Intensifying natural capital, they amplify its beneficial effects for both individuals and the community. This is why we introduced the term "upscaling", associating it with Biophilia. The simplest definition of upscaling refers to expanding or increasing the scale, scope, or impact of a particular phenomenon [126]. A more detailed and ambitious notion implies delivering higher quantity and quality to a larger target over a wider geographical area, more quickly, more equitably, and more lasting [127]. After exploring biophilic effects and the related benefits of urban living, we propose Biophilia Upscaling to emphasize the need to extend Biophilia beyond current limits, moving from concept to implementation (applying), from building to city scale (quantitative upscaling), to make its benefits more diversified and impactful for everyone, everywhere (qualitative upscaling). Through these three actions, Biophilia Upscaling exactly matches the three-metric approach guiding this SLR. The existing literature indicates numerous application metrics supporting a robust Biophilia Upscaling through research by design. From BD to BU, we present an overview of design criteria or guidelines laid out chronologically and across scales by leading BET scholars, including the following integrations.

4.3.1. Biophilic Design

Based on the literature cornerstones, we have identified the evolution of the BD theoretical framework in four major steps (Table 6). While providing different tools, they aim at achieving the primary goals of BD: creating good habitats for people, nature, and living organisms within modern cities; providing settings, activities, and processes that encourage interspecies interaction to mutually enhance living conditions; addressing the deficiencies of contemporary design, which alienated us from nature; and highlighting the benefits of applying Biophilia to the built environment [16,19,47]. However, achieving high-performance BD requires consistent adherence to specific biophilic features, as emphasized by Kellert [17]. He first recognized the need to define BD through two dimensions, six elements, and 72 attributes [16]. This framework has been conceived as a valuable toolkit for designers, aiding in their understanding and implementation of Biophilia. As the second benchmark, Browning et al. [61] suggested a simplified approach grounded in three categories of space–nature interrelation (nature in the space, natural analogs, and nature of the space), with 14 categories and patterns aimed at prioritizing users' well-being. They were clearly inspired by Kellert's guidance [16], as outlined in Table 6, where colorful check marks match the common principles of the two frameworks. Later, Kellert together with Calabrese [19] simplified the original theory in the awareness that BD establishes dynamic living spaces able to adapt to different users and their changing needs over time. To this end, they delivered a novel scheme focused on human perception, thus underlining the role of individuals as the essential perceiving subjects in interacting with nature through three potential experiences: direct, indirect, and space and place. Merging the first two frameworks by Kellert [16] and Browning [61], Kellert and Calabrese [19] reduced the initial 72 BD indicators to 24 experiences and attributes; namely, they turn out to be a selection from the first panel, as indicated by the bold terms in Table 6. As for the fourth framework, Kellert [17] proposed a more complete paradigm for successful

BD applications. Conceived as a theoretical-practical guide, it comprises 40 practices related to both the meaningful rationale of BD (values and principles) and the best practices (experiences, elements, application places, and building typologies) to build indoor and outdoor settings or landscapes [17]. Afterward, supplementary metrics were released to facilitate BD applications. Despite referring to the basic approach, they focus on specific aspects or serve as checking indicators of BD quality. Further progress in BD was suggested by McGee et al. [91] in the form of the Biophilic Interior Design Matrix, comprising six elements and 54 attributes inspired by Kellert's scheme. Designed specifically for indoor applications, it serves as a resource for interior designers who approach Biophilia in a "do-it-yourself" mode. Lee and Park [122] proposed a 15-factor hybrid framework for residential environments that merges physical and digital design techniques so as to reach a larger audience, expanding the range of biophilic experiences on three building scales (residential unit, building, and complex scale). Indoor settings constitute the main location where they tested Biophilia in Virtual Reality. Mollazadeh and Zhu [106] systematized a series of key elements helping to design virtual biophilic settings for BD indoor implementation. While referring to Browning's three categories of human–nature experience, their factors were tested to simulate only direct contact with nature (nature in the space) within digital environments. Xue et al. [20] developed a 42-item qualitative framework that blends BD features with standards from green building rating systems, such as LEED and BREEAM. This framework is intended to guide the design process toward creating healthier solutions. Lastly, Vileniske et al. [121] carried out an initial classification of biophilic buildings that reveals the strong correlation between architecture and biophilic properties in terms of human–nature interaction.

Table 6. Evolution of Biophilic Design framework in four steps.

DIMENSIONS, ELEMENTS,ANDATTRIBUTES (Kellert et al., 2008 [16])					
Organic or Naturalistic				Place-based or Vernacular	
Environmental features	Natural shapes and forms	Natural patterns and processes	Light and space	Place-based relationships	Evolved human–nature relationships
Color **Water** ✔ **Air** ✔ **Sunlight** **Plants** **Animals** Natural materials ✔ **Views and vistas** Façade greening Geology and **landscape** Habitats and **ecosystems** **Fire**	**Botanical motifs** Tree and columnar supports **Animal motifs** **Shells and spirals** Oval and tubular form Arches, vaults, domes **Shapes resisting straight lines and right angles** **Simulation of natural features** Biomorphology ✔ Geomorphology **Biomimicry**	Sensory variability ✔ **Information richness** **Age, change, and the patina of time** Growth and efflorescence Central focal point Patterned wholes Bounded spaces **Transitional spaces** Linked series/chains **Integration of parts to wholes** Complementary contrasts Dynamic balance and tension Fractals Hierarchical ratios/scales	**Natural light** ✔ Filtered and diffused light ✔ Light and shadow ✔ Reflected light ✔ Light pools ✔ Warm light ✔ Light as shape and form ✔ Spaciousness Spatial variability Space as shape and form Spatial harmony Inside–outside spaces	Geographic connection to place ✔ Historic connection to place **Ecological connection to place** ✔ **Cultural connection to place** Indigenous materials **Landscape orientation** Landscape features defining building form Landscape ecology Integration of culture and ecology Spirit of place Avoiding placelessness	**Prospect and refuge** ✔ **Order and complexity** ✔ Curiosity and enticement Change and metamorphosis Security and protection ✔ Mastery and control Affection and attachment Attraction and beauty Exploration and discovery Information and cognition Fear and awe Reverence and spirituality
CATEGORIES ANDPATTERNS (Browning et al., 2014 [61])					
Nature in the Space		Natural Analogues		Nature of the Space	
Visual connection with nature ✔ Non-visual connection with nature ✔ Non-rhythmic sensory stimuli ✔ Thermal & airflow variability ✔ Presence of water ✔ Dynamic and diffuse light ✔ Connection with natural systems✔		Biomorphic forms and patterns ✔ Material connection with nature ✔ Complexity and order ✔		Prospect ✔ Refuge ✔ Mystery Risk/Peril ✔	

Table 6. *Cont.*

EXPERIENCES AND ATTRIBUTES (Kellert and Calabrese, 2015 [19])		
Direct Experience of Nature	Indirect Experience of Nature	Experience of Space and Place
Light **Air** **Water** **Plants** **Animals** Weather **Natural landscapes and ecosystems** **Fire**	**Images of nature** **Natural materials** **Natural colors** **Simulating natural light and air** **Naturalistic shapes and forms** **Evoking nature** **Information richness** **Age, change, and the patina of time** **Natural geometries/Biomimicry**	**Prospect and refuge** **Organized complexity** **Integration of parts to wholes** **Transitional spaces** Mobility and **wayfinding** **Cultural and ecological attachment to place**

PRACTICE OFBD (Kellert, 2018 [17])				
Values	Principles	Experiences	Elements	Application places and types
Aesthetic/Attraction Dominionistic/Control Humanistic/Affection Moralistic/Spirituality Naturalistic/Contact Scientific/Knowledge Symbolic/Inspiration Negativistic/Aversion Utilitarian/Exploitation	Human adaptations Integrated settings Engagement and immersion in nature Ethical, cultural, ecological values Emotional attachments to structures, places, landscapes Community membership Multiplicity of settings Authentic experience of nature Enhancement of human–nature and interspecies relationship	Direct Indirect Space and Place	Views Images Materials Texture Color Shapes and Forms Natural geometries Biomimicry	Interior and exterior settings Landscapes Prevalent building typologies Housing Educational spaces Working spaces Healing spaces Hospitality Shopping Center Sacred spaces Transitional spaces

The chronological evolution of Biophilic Design follows four main frameworks. In bold type are analogies between the first conception by Kellert et al. [16] and its following upgrade developed in cooperation with Calabrese [19]. The checkmark highlights similar criteria between the first two theoretical models, matching them by color.

4.3.2. Biophilic Urbanism

As the most recent development in BET evolution, there has been a notable surge in literary interest in BU over the past decade. As Kellert [72] suggested, simply bringing nature into the city or extending the potential of BD beyond the building boundaries is not enough to turn the urban habitat into a biophilic city. An effective application of Biophilia at the urban scale requires consistent measurements backed by a fixed theoretical framework, which provides principles and tools for managing complex urban contexts.

Recognized as the pioneer of BU, Beatley formulated a scalable Biophilia framework, shifting from BD to BU in three stages. Just in the length of a paper, he first issued practical strategies and opportunities for implementing Biophilia in the built environment at three scales: biophilic buildings and homes; biophilic neighborhoods; and biophilic cities and metropolitan areas [38]. Subsequently, he structured these concepts into a guiding manual to assist city makers with a smoother transition toward biophilic cities. This manual encompassed both qualitative and quantitative indices, structured across four dimensions (conditions and infrastructure; activities; attitudes and knowledge; and institutions and governance), applied at six socio-spatial scales (building, block, street, neighborhood, community, and city/region/bioregion), defining 22 minimum standards of Biophilia and 31 specific Biophilic Urban Design elements for urban areas (Table 7). Lastly, Beatley complemented the BU framework with updated concepts of biophilic cities (Table 2), even showcasing best practices, case studies, and successful initiatives all around the world [21]. His argument underscored the necessity for a new mindset and conduct at the individual, social, and political levels. Thus, he provided a list of 12 Ways to Experience Nature in the City, inside or outside, encompassing psychological, cultural, and social experiences. He also advocated for the role of digital technology as an innovative vehicle to empower biophilic benefits via devices and domotics, offering multisensory experiences of nature: the core of Biophilia [39]. As shown in bold types (Table 7), such a systemic approach incorporates several key elements already featured in his previous BU theories [21,38]. Through this thematic handbook, he sought to overcome the existing constraints of Biophilia Upscaling, especially in addressing urban planning toward a biophilic agenda [39]. Following him, Newman played a significant role in advancing this complex process. He laid the foundation for the transformation of Green Urbanism into BU, using Singapore as a paradigmatic example of shifting from a traditional "garden or green city" to a biophilic "city in a garden" [22,59]. To supplement their findings, Beatley and Newman [12] jointly made the latest advancement in Biophilia Upscaling: they extended BU to a bioregional scale to emphasize its contribution to making cities more resilient, even enhancing both social and natural capital [77]. Continuing in the same vein, subsequent research has produced additional metrics for the effective application of BU, addressing practical challenges related to scalability, environmental concerns, and socioeconomic priorities. Cabanek et al. [103] proposed an integrated Biophilic Streets Design Framework aimed at integrating BU into the urban fabric, beginning at the street level as the gateway to a biophilic city. On a larger scale, the application of BU was examined through its ecosystem capabilities, identifying biophilic services for the mutual benefit of citizens and the natural environment [78]. Lee and Kim [112] developed an advanced framework that categorizes BU elements as climate adaptation and mitigation strategies across three dimensions (macro, meso, and micro) and spatial scales (region and city; neighborhood and street; and building). It also included different biophilic methods (natural, technical, and functional) to make a city climate-proof. By examining the relationship between biophilic city indicators and smart city indicators, Tarek and Ouf [23] proposed a comprehensive framework aimed at achieving urban resilience. Reeve et al. [64] indexed biophilic benefits as functional features, highlighting the valuable contribution of BU in renewing city planning by seamlessly integrating urban greenery and development across scales. In conclusion, it is worth noting the geographical analysis of BU implementation carried out by Carter and Henríquez [111]. Leveraging Beatley's indicators within the category "institutions and biophilic governance", they systematically mapped BU initiatives globally, thus identifying the most successful endeavors in economically advanced countries where governments actively promoted them.

Table 7. Evolution of Biophilic Urbanism framework.

BIOPHILIC CITY DIMENSION ANDINDICATORS (Beatley, 2011 [21])			
Conditions and Infrastructure	Activities	Attitudes and Knowledge	Institutions and Governance
Proximity to parks and green spaces (≥1 park by 100 m per capita) Percentage of land area covered by trees or other vegetation in wild/semi-wild condition (≥10%) and fair distribution of nature Forest canopy cover (>20%) Number of green design features (≥1/1000 inhab.) Walking trails (1 Mi/10,000 inhab.) Community garden (≥1/2500 inhab.) Existence of connected, integrated, ecological network (≥1) Extent flora and fauna, natural images, shapes, and forms are employed in architecture	**Percentage of population active in nature or outdoor clubs or organizations** (%, $\geq\frac{1}{4}$ pop involved in 1 club) **Population engaged in nature restoration and volunteer efforts** (1–5% pop) **Average portion of the day spent outside** (≥15% daily time) **Residents active in gardening** (≥40%) Extended outdoor playtime in schools (45′/teaching segment)	**Percentage of residents who express care and concern for nature** (≥1/3 pop) **Percentage of residents aware of common native species of flora and fauna** (≥1/3 pop) Learning activity in nature (≥30′/daily time)	**Existence of a biodiversity plan including design and planning regulations to promote biophilic conditions** (≥1) **Biophilic institutions and cultural/training services** (≥1 history museum + 1 botanical garden/municipality, at least) Number of educational programs in local schools aimed at teaching about nature (≥1/2 of city public schools) Percent of municipal budget devoted to biophilic programs (≥5% city budget) **Biophilic building and planning codes** (≥1/building or municipality) Biophilic pilot projects and actions (≥5/city)

Table 7. *Cont.*

BIOPHILIC URBAN DESIGN ELEMENTS ACROSSSCALES (Beatley, 2011; partially featured in Beatley, 2009 [21,38])					
Building	Block	Street	**Neighborhood**	Community	**City**/Region/Bioregion
Green rooftops **Sky gardens and green atria** **Rooftop gardens** **Green walls/façade and vertical garden** Daylit interior spaces	**Green courtyards** Clustered housing around green areas **Native species yards and spaces**	**Green streets** **Sidewalk gardens** **Urban trees** Low-impact development Vegetated swales and skinny streets Edible landscaping High degree of permeability	**Stream daylighting, stream restoration** **Urban forests** Ecology parks **Community gardens** **Neighborhood parks and pocket parks** Greening grayfields and brownfields	Urban creeks and riparian areas Urban ecological networks Green schools **City tree canopy** **Community forest and community orchards** Greening utility corridors	River systems and floodplains Riparian areas Regional greenspace systems Greening major transport corridors
WAYSTOEXPERIENCE NATURE IN THECITY (Beatley, 2016 [39])					
Outside			**Inside**		
Psychical		Psychological/Cultural/Social		Psychical	Psychological/Cultural/Social
Watching, seeing, listening to actual nature **Hiking, camping, spending time out of doors** Feeling the wind, rain, mist on one's body Contemplating nature or a memory of a previous experience		**Training about nature** **Participating in a nature club or organization outdoors** Purposeful eco-enjoyment of outdoor nature activities (gardening, tree planting, cleaning up)		Watching nature through a window Watching images of nature on a computer screen Experiencing indoor nature	**Training about nature** **Participating in nature clubs or organizations indoors**

The temporal frameworks according to Beatley's works [21,39], in bold type are the elements already featured in 2009 [38].

5. Discussion

The following discussion is organized to address the three research questions. We first dealt with Biophilia theoretically, as a concept and research field; then, we addressed it through its qualitative, quantitative, and applicative effects.

This SLR uncovered Biophilia as a complex and not fully explored research field, and its potential is expressed in both opportunities and limitations for each metric analyzed. Overall, the review process highlighted a gap between theoretical and practical aspects, with a greater emphasis on theory. Similarly, Basic Research dominates over evidence-based research in this domain. From a temporal perspective, the peer-reviewed literature has seen a growing interest in Biophilia-related topics, especially over the last decade. Studies have primarily focused on Biophilia and BD rather than BU, although there was a notable peak in the past three years (Figure 2). Among the reviewed items, only a few cases concurrently addressed both BD and BU, but they rarely apply an approach oriented toward Biophilia Upscaling. Notably, the majority of studies allocated a significant portion of their content to background information, underlining the relatively brief history of BET. This confirms that Biophilia, whether as a topic or a research field, remains less known, despite its wide discussion and acceptance across scientific fields. In the disciplinary domain, applied and hybrid science are increasingly directing their attention toward Biophilia, whereas gaps are noticeable in the realm of political-economic and digital science. From a geographical perspective, the literature indicated a prevailing northern orientation, with the US, the BET birthplace, in theories and applications.

In support of Biophilia as an objective research field, it was explored through the lens of biophilic effects, validated by scientific evidence across items, sectors, and dimensions. This qualifies BD and BU as effective tools for science-based renewal in architecture and urban planning. While most research adhered to solid disciplinary theories to support BET, including an evolution-driven approach, its biological foundation still presents certain weaknesses. Based on this review, we contend that culture, background, and expertise play a key role in optimizing biophilic inclinations. There is a mismatch among sectors of biophilic qualities: a predominance of research focused on health and well-being anchors Biophilia in the individual sphere, where the human–nature connection is easily monitored. On the other side, evidence of biophilic effects in macrosystems (urban, social, environmental, and economic) is lacking or requires a longer term to be assessed.

Quantifying Biophilia has emerged as the major knowledge gap in the field. Most proposed biophilic indicators have a qualitative or descriptive focus rather than a quantitative one. Derived tools are eligible for specific measurements of biophilic effects, but they have limitations, as researchers stated. Additionally, Ad hoc Tools are more specific and essential in controlling a high number of variables involved within integrated biophilic systems. Measuring the biophilic impact is crucial for understanding its full potential and for making informed decisions.

Regarding the application of Biophilia applications, we observed a disparity between BD and BU in the literature as much as in real applications, partly due to the shorter lifespan of the latter. However, there is a lack of studies discussing how to adapt biophilic patterns to different building types or how to relate BD and BU to scales, architectural expressions, styles, representation, urban form, and tectonics. While BD and BU assume affiliation with all living forms, their application metrics primarily focus on greenery; the biophilic experience with animals or other living systems is addressed only marginally. Best practices and initiatives worldwide confirm the potential for enjoying benefits from BD and BU everywhere, but there is insufficient evidence to demonstrate that guidelines and features are universally applicable, transferable, and valid in different biomes. An upgrade built on various geographical contexts may be advisable. Even factors like age and gender should be considered in BD and BU applications. Both BD and BU serve as tangible supports to Biophilia, facilitating multisensory exchanges with the natural world, allowing for multiple responses simultaneously. Digital technology also amplifies biophilic effects, making further implementation in virtual environments highly recommended.

Biophilic cities translate the concept of Biophilia into a new urban model founded on the following:

- Quality-oriented approach: Biophilic cities pursue the strategic integration of nature and the built environment through BD and BU, enhancing urban livability, citizens' health and well-being, along with the performance of both natural and anthropic systems.
- Sustainable thinking: Biophilic cities combine multiple urban systems using nature as a core resource to achieve ecological, social, and economic sustainability, while also enhancing climate resilience. A biophilic city supports the 2030 Agenda in meeting SDGs.
- Responsibility: Biophilic cities are living laboratories where citizens proactively participate in their successful fulfillment by preserving natural capital. City makers and investors are also responsible for creating and ensuring biophilic conditions across the city.
- Reciprocity: As an organic system, a biophilic city operates through reciprocal interactions between species and their environments, leading to shared benefits within a general domino effect.

Renewing urban planning with a foundation in Biophilia requires a systematic change in individual mindset and lifestyle, entailing significant cultural, social, and economic costs at the community level. To accelerate such a transformation, we promote Biophilia Upscaling as a means to make biophilic effects real, livable, and affordable via BD and BU (application); increase their number through scales and validate them through measuring tools (quantitative upscaling); and diversify them by targets and experiences (qualitative upscaling). As illustrated in Figure 5, we matched biophilic effects and urban scales. This attempt shows how Biophilia Upscaling aids in maximizing direct or indirect benefits across the main dimensions analyzed (physical, psychological, social, environmental, and economic). Research indicates that Biophilia Upscaling is already being implemented to achieve a biophilic city model, but it remains an open challenge due to the constraints mentioned above.

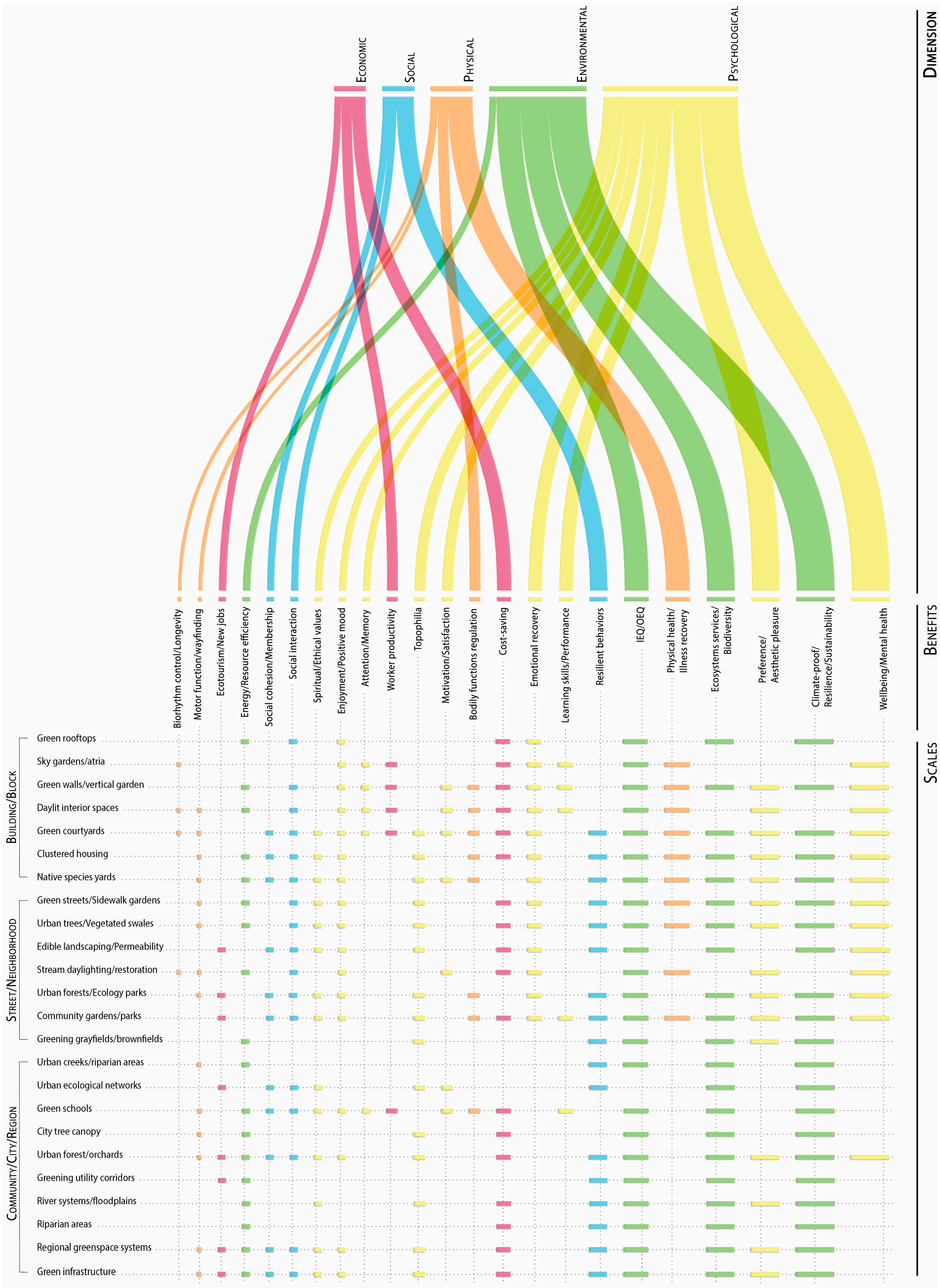

Figure 5. Upscaling Biophilia: relations between benefits and urban scales. Flow-paths are determined by dimension-sorted items.

6. Conclusions

This paper presents a systematic review on Biophilia, Biophilic Design (BD), and Biophilic Urbanism (BU) based on disciplinary, metric, and spatial dimensions. It offers a comprehensive framework of 60 years of literature, tracing its evolution from its initial foundation to its contemporary applications in the built environment through BD and BU. It sheds light on notions and practices that substantiate an emerging research field, aiming to address some of the current knowledge gaps subjected to ongoing debate. They pertain to the concept of Biophilia, scientific objectivity, measurability, and the upscaling process. This aspect makes this work timely. The theoretical-practical perspective has enabled us to emphasize the dual nature of Biophilia, Basic and Applied Research. Its conceptual evolution has paralleled its practical application. This SLR represents an ambitious effort to condense a vast body of research, including the foundational works by Biophilia pioneers and the most recent peer-reviewed literature, with the intent to underscore the interdisciplinary interest in this subject. As a further advancement in the field, we propose a novel definition of Biophilia that encompasses its essential aspects (humans, nature, interactions, and effects), emphasizing its benefits for humans and urban livability. Nevertheless, the primary research limitations are attributable to the unprecedented attempt to provide an overall advancement of the state of the art, while constraining the scope due to keyword choices and the fixed selection criteria that excluded research relevant to Biophilia but not explicitly referencing it. Likewise, the fixed selection criteria (databases, publications type or stage, timing, language, access, etc.) may have influenced the obtained results. On the other hand, its innovation lies in adopting a three-metric approach and a multidimensional perspective, while addressing three critical gaps in the research field: scientific objectivity and validity, measurability, and the upscaling process. This method helped us to systematically review materials and analyze the multiple advantages of Biophilia through the lens of quality, quantity, and application. The qualitative analysis of biophilic effects highlighted the relevance of Biophilia, showcasing its multidimensional and cross-sectoral impact; it also strengthened its scientific rationale, supported by evidence-based studies. The quantitative analysis demonstrated the objectivity and computability of Biophilia through various measurement tools, effectively mitigating the bias stemming from its subjective nature. Lastly, the applicative analysis showed how to translate Biophilia into living spaces, validating BD and BU as applied sciences capable of renewing Urban Design and Planning toward a biophilic city model. A special emphasis has been placed on Biophilia Upscaling as a strategy to maximize its direct and indirect benefits across urban scales and promote BU, thus enhancing urban livability and expediting a paradigm shift in city planning. The discussion underlined the current knowledge gaps within this relatively new research field that warrant further insights. Based on this, we recommend future insights in this emerging research field aimed at delving into the less-investigated aspects so far: BU and large-scale applications, assessment methods, biophilic strategies for climate resilience, and digital and multisensorial experiences. BD and BU have positive implications for everyday life: they can assist designers, planners, and decision makers in addressing the urban agenda toward higher environmental and social standards. This is crucial in metropolises conceived as bioregional systems, where nature plays a key role in ensuring ecosystem services and citizens' well-being. In conclusion, we advocate for Biophilia as the most ecological and sustainable approach to promote urban development, in compliance with the needs of people and nature and their mutual interdependencies.

Author Contributions: Conceptualization, D.L. and A.v.T.; methodology, D.L.; review process, D.L.; formal analysis, D.L.; investigation, D.L.; data curation, D.L; writing—original draft preparation, D.L.; writing—review and editing, D.L. and A.v.T.; visualization, D.L.; supervision, A.v.T. and C.R.; project administration, D.L. and A.v.T.; funding acquisition, D.L. and A.v.T. (BIO-POLIS project). All authors have read and agreed to the published version of the manuscript.

Funding: This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 101026318. This article reflects only the author's view. The Research Executive Agency (REA), under the powers delegated by the European Commission, is not responsible for any use that may be made of the information it contains.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data used to support the findings of this study are included in the manuscript. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Search Syntax

The search syntax has been performed through four main keywords: Biophilia; biophilic benefit; Biophilic Design; and Biophilic Urbanism. To narrow the first coarse selection, further operative terms have been assigned to each of them in a way that composes meaningful simple word code (or locution) and related selection blocks. They included topic-related words such as nature, biophilic cities, biophilic architecture, green space, urban nature, quality of life, quantitative analysis, urban biodiversity, well-being, built environment, nature-people relation, health, green infrastructure, and urban studies. The Boolean search extended the number of results, matching them with "AND" and "OR", as common operators. Deriving more pertinent database outputs, the search was limited to the following subject areas: Social Science, Environmental Science Technology/Design, Earth and Planetary Science, Engineering, Energy, Arts and Humanities, Psychology, Medicine, Economy, Politics, and Decision Science. The four blocks of search syntax are described in detail as follows, including the founded items and their time range selection.

Appendix B. Exclusion Filters

To narrow the total number of items found to those analyzed, some records have been excluded based on the following preliminary filters:

a. Publication type (conference proceedings, thesis/dissertations, editorials, notes);
b. Publication stage (in press or non-indexed);
c. Language (items not in English);
d. Timing (starting from 1980);
e. Open access resources (not full text and images included);
f. Relevance (not disciplinary/subject area correspondence);
g. Basic topic requirement (keywords occur at least once in the title or abstract to guarantee significant usefulness and pertinence).

References

1. Panlasigui, S.; Spotswood, E.; Beller, E.; Grossinger, R. Biophilia beyond the Building: Applying the Tools of Urban Biodiversity Planning to Create Biophilic Cities. *Sustainability* **2021**, *13*, 2450. [CrossRef]
2. Russo, A.; Cirella, G. Modern Compact Cities: How Much Greenery Do We Need? *Int. J. Environ. Res. Public Health* **2018**, *15*, 2180. [CrossRef] [PubMed]
3. Nilon, C.; Aronson, M.; Cilliers, S. Planning for the Future of Urban Biodiversity: A Global Review of City-Scale Initiatives. *BioScience* **2017**, *67*, 332–342. [CrossRef]
4. Andersson, E.; Barthel, S.; Borgström, S. Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services. *Ambio* **2014**, *43*, 445–453. [CrossRef]
5. Henriquez, L.; van Timmeren, A. *Under Pressure: Water and the City*; TU Delft: Delft, The Netherlands, 2017.
6. Reed, C.; Lister, N.M.E. *Projective Ecologies*; Harvard University Graduate School of Design: Cambridge, MA, USA, 2014.
7. Bolten, B.; Barbiero, G. Biophilic Design: How to Enhance Physical and Psychological Health and Wellbeing in Our Built Environments. *Vis. Sustain.* **2020**, *13*, 11–16.
8. van Timmeren, A.; Amenta, L.; Russo, M. Afterword. In *Regenerative Territories: Dimensions of Circularity for Healthy Metabolism*; Springer: Cham, Switzerland, 2022; Volume 128.
9. Novák, N.; Kőmíves, P.; Harangi-Rákos, M.; Pető, K. The Role of Rural Areas in the Preservation of Health. *Int. Rev. Appl. Sci. Eng. IRASE* **2020**, *11*, 157–166. [CrossRef]
10. Klepeis, N.E.; Nelson, W.C.; Ott, W.R.; Robinson, J.P.; Tsang, A.M.; Switzer, P.; Behar, J.V.; Hern, S.C.; Engelmann, W.H. The National Human Activity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants. *J. Expo. Sci. Env. Epidemiol.* **2001**, *11*, 231–252. [CrossRef]
11. White, M.; Alcock, I.; Grellier, J.; Wheeler, B.; Hartig, T. Spending at Least 120 Minutes a Week in Nature Is Associated with Good Health and Wellbeing. *Sci. Rep.* **2019**, *9*, 7730. [CrossRef]
12. Beatley, T.; Newman, P. Biophilic Cities Are Sustainable, Resilient Cities. *Sustainability* **2013**, *5*, 3328–3345. [CrossRef]
13. Fromm, E. *The Heart of Man: Its Genius for Good and Evil*; Harper and Row: New York, NY, USA, 1964.
14. Kellert, S.R.; Wilson, E.O. *The Biophilia Hypothesis*; Island Press: Washington, DC, USA, 1993.
15. Wilson, E. *Biophilia: The Human Bond with Other Species*; Harvard University Press: Cambridge, MA, USA, 1984.
16. Kellert, S.; Heerwagen, J.; Mador, M. *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*; Wiley: Hoboken, NJ, USA, 2008.
17. Kellert, S.R. *Nature by Design: The Practice of Biophilic Design*; Yale University Press: New Haven, CT, USA, 2018.

18. Berkebile, B.; Fox, B.; Hartley, A. Reflections on Implementing Biophilic Design. In *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life*; Kellert, S.R., Heerwagen, J., Mador, M., Eds.; Wiley: Hoboken, NJ, USA, 2008; pp. 345–354.
19. Kellert, S.; Calabrese, E. *The Practice of Biophilic Design*; Terrapin Bright Green, LLC: New York, NY, USA, 2015.
20. Xue, F.; Lau, S.; Gou, Z.; Song, Y.; Jiang, B. Incorporating Biophilia into Green Building Rating Tools for Promoting Health and Wellbeing. *Environ. Impact Assess. Rev.* **2019**, *76*, 98–112. [CrossRef]
21. Beatley, T. *Biophilic Cities: Integrating Nature into Urban Design and Planning*; Island Press: Washington, DC, USA, 2011.
22. Newman, P. Green Urbanism and Its Application to Singapore. *Environ. Urban. Asia* **2010**, *1*, 149–170. [CrossRef]
23. Tarek, S.; Ouf, A. Biophilic Smart Cities: The Role of Nature and Technology in Enhancing Urban Resilience. *J. Eng. Appl. Sci.* **2021**, *68*, 1–22. [CrossRef]
24. Söderlund, J. *The Emergence of Biophilic Design*; Cities and Nature; Springer Nature: Cham, Switzerland, 2019.
25. Andreucci, M.; Lorder, A.; Brown, M. Exploring Challenges and Opportunities of Biophilic Urban Design: Evidence from Research and Experimentation. *Sustainability* **2021**, *13*, 4323. [CrossRef]
26. Cardinali, M.; Beenackers, M.A.; van Timmeren, A.; Pottgiesser, U. Preferred Reporting Items in Green Space Health Research: Guiding Principles for an Interdisciplinary Field. *Environ. Res.* **2023**, *228*, 115893. [CrossRef] [PubMed]
27. Taylor, R.P. The Potential of Biophilic Fractal Designs to Promote Health and Performance: A Review of Experiments and Applications. *Sustainability* **2021**, *13*, 823. [CrossRef]
28. Mora, L.; Deakin, M.; Bolici, R. The First Two Decades of Smart-City Research: A Bibliometric Analysis. *J. Urban Technol.* **2017**, *24*, 3–27. [CrossRef]
29. Liberati, A.; Altman, D.; Tetzlaff, J.; Mulrow, C. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. *PLoS Med.* **2009**, *6*, e1000100. [CrossRef] [PubMed]
30. Yigitcanlar, T.; Kamruzzaman, M.; Fothc, M. Can Cities Become Smart without Being Sustainable? A Systematic Review of the Literature. *Sustain. Cities Soc.* **2019**, *45*, 348–365. [CrossRef]
31. Fromm, E. *The Anatomy of Human Destructiveness*; Holt, Rinehart and Winston: New York, NY, USA, 1973.
32. Wilson, E. *Biophilia*; Harvard University Press: Cambridge, MA, USA, 1979.
33. Wilson, E. Biophilia and the Conservation Ethic. In *The Biophilia Hypothesis*; Shearwater Books: Washington, DC, USA, 1993; pp. 31–40.
34. Wilson, E. *Naturalist*; Shearwater Books: Washington, DC, USA, 1994.
35. Kellert, S. *Kinship to Mastery: Biophilia in Human Evolution and Development*; Island Press: Washington, DC, USA, 2008.
36. Ryan, C.; Browning, W. Biophilic Design. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R., Ed.; Springer: New York, NY, USA, 2018; p. 44.
37. Beatley, T. Biophilic Design. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R., Ed.; Springer: New York, NY, USA, 2018; p. 276.
38. Beatley, T. Biophilic Urbanism: Inviting Nature Back to Our Communities and Into Our Lives. *William Mary Environ. Law Policy Rev.* **2009**, *34*, 209.
39. Beatley, T. *Handbook of Biophilic City Planning and Design*; Island Press: Washington, DC, USA, 2016.
40. Beatley, T. Biophilic Cities. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R., Ed.; Springer: New York, NY, USA, 2020; p. 280.
41. Beatley, T. Biophilic Cities Network. In *Encyclopedia of Sustainability Science and Technology*; Meyers, R., Ed.; Springer: New York, NY, USA, 2020; p. 284.
42. Santas, A. Aristotelian Ethics and Biophilia. *Ethics Environ.* **2014**, *19*, 95–121. [CrossRef]
43. Krčmářová, J.E.O. Wilson's Concept of Biophilia and the Environmental Movement in the USA. *Kladyán* **2009**, *6*, 4–17.
44. Knobel, P.; Dadvant, P.; Maneja-Zaragoza, R. A Systematic Review of Multi-Dimensional Quality Assessment Tools for Urban Green Spaces. *Health Place* **2019**, *59*, 102198. [CrossRef]
45. Zare, G.; Faizi, M.; Baharvand, M. A Review of Biophilic Design Conception Implementation in Architecture. *J. Des. Built Environ.* **2021**, *21*, 16–36. [CrossRef]
46. Zhong, W.; Schröder, T.; Bekkering, J. Biophilic Design in Architecture and Its Contributions to Health, Well-Being, and Sustainability: A Critical Review. *Front. Archit. Res.* **2022**, *11*, 114–141. [CrossRef]
47. Kahn, P. *The Human Relationship with Nature: Development and Culture*; MIT Press: Cambridge, MA, USA, 1999.
48. Ulrich, R. Effects of Gardens on Health Outcomes: Theory and research. In *Healing Gardens: Therapeutic Benefits and Design Recommendations*; Cooper, M.C., Barnes, M., Eds.; John Wiley & Sons: New York, NY, USA, 1999; pp. 27–86.
49. Gullone, E. The Biophilia Hypothesis and Life in the 21st Century: Increasing Mental Health or Increasing Pathology? *J. Happiness Stud.* **2000**, *1*, 293–321. [CrossRef]
50. Kahn, P.; Kellert, S. *Children and Nature: Psychological, Sociocultural and Evolutionary Investigations*; MIT Press: Cambridge, MA, USA, 2002.
51. Besthorn, F.; Saleebey, D. Nature, Genetics and the Biophilia Connection: Exploring Linkages with Social Work Values and Practice. *Adv. Soc. Work* **2003**, *4*, 1–18. [CrossRef]
52. Tsunetsugu, Y.; Miyazaki, Y.; SatoH, H. Physiological Effects in Humans Induced by the Visual Stimulation of Room Interiors with Different Wood Quantities. *J. Wood Sci.* **2007**, *53*, 11–16. [CrossRef]

53. Grinde, B.; Patil, G. Biophilia: Does Visual Contact with Nature Impact on Health and Well-Being? *Int. J. Environ. Res. Public Health* **2009**, *6*, 2332–2343. [CrossRef]
54. Hinds, J.; Sparks, P. The Affective Quality of Human-Natural Environment Relationships. *Evol. Psychol.* **2011**, *9*, 451–469. [CrossRef]
55. Derr, V.; Lance, K. Biophilic Boulder: Children's Environments That Foster Connections to Nature. *Child. Youth Environ.* **2012**, *22*, 112–143. [CrossRef]
56. Tibdall, K. Urgent Biophilia: Human-Nature Interactions and Biological Attractions in Disaster resilience. *Ecol. Soc.* **2012**, *17*, 5.
57. Browning, B.; Garvin, C.; Fox, B.; Cook, R. *The Economics of Biophilia: Why Designing with Nature in Mind Makes Financial Sense*; Terrapin Bright Green: New York, NY, USA, 2012.
58. Jones, D. 'The Biophilic University': A de-Familiarizing Organizational Metaphor for Ecological Sustainability? *J. Clean. Prod.* **2013**, *48*, 148–165. [CrossRef]
59. Newman, P. Biophilic Urbanism: A Case Study on Singapore. *Aust. Plan.* **2013**, *51*, 47–65. [CrossRef]
60. Ignatieva, M.; Ahrné, K. Biodiverse Green Infrastructure for the 21st Century: From "Green Desert" of Lawns to Biophilic Cities. *J. Archit. Urban.* **2013**, *37*, 1–9. [CrossRef]
61. Browning, W.; Ryan, C.; Clancy, J. *14 Patterns of Biophilic Design*; Terrapin Bright Green: New York, NY, USA, 2014.
62. Capaldi, C.; Dopko, R.; Zelenski, J. The Relationship between Nature Connectedness and Happiness: A Meta-Analysis. *Front. Psychol.* **2014**, *5*, 976. [CrossRef]
63. Revell, G.; Anda, M. Sustainable Urban Biophilia: The Case of Greenskins for Urban Density. *Sustainability* **2014**, *6*, 5423–5438. [CrossRef]
64. Reeve, A.; Desha, C.; Hargreaves, D.; Hargroves, K. Biophilic Urbanism: Contributions to Holistic Urban Greening for Urban Renewal. *Smart Sustain. Built Environ.* **2015**, *4*, 215–233. [CrossRef]
65. Gillis, K.; Gatersleben, B. A Review of Psychological Literature on the Health and Wellbeing Benefits of Biophilic Design. *Buildings* **2015**, *5*, 948–963. [CrossRef]
66. Kalvaitis, D.; Monhardt, R. Children Voice Biophilia: The Phenomenology of Being in Love with Nature. *J. Sustain. Educ.* **2015**, *9*, 21.
67. Beery, T.; Jönsson, K.; Elmberg, J. From Environmental Connectedness to Sustainable Futures: Topophilia and Human Affiliation with Nature. *Sustainability* **2015**, *7*, 8837–8854. [CrossRef]
68. Gochman, S. *Seeking Parks, Plazas and Spaces: The Allure of Biophilia in Cities*; Terrapin Bright Green: New York, NY, USA, 2016.
69. Berto, R.; Barbiero, G.; Pasini, M.; Unema, P. Biophilic Design Triggers Fascination and Enhances Psychological Restoration in the Urban Environment. *J. Biourbanism* **2016**, *1*, 27–34.
70. Soga, M.; Gaston, K.; Yamaura, Y.; Kurisu, K.; Hanaki, K. Both Direct and Vicarious Experiences of Nature Affect Children's Willingness to Conserve Biodiversity. *Int. J. Environ. Res. Public. Health* **2016**, *13*, 529. [CrossRef]
71. Santiago Fink, H.; Kaltenegger, I. Integration of Mother Nature into Smart Buildings. In *Integration of Nature and Technology for Smart Cities*; Springer: Cham, Switzerland, 2016; pp. 225–261.
72. Kellert, S. Biophilic Urbanism: The Potential to Transform. *Smart Sustain. Built Environ.* **2016**, *5*, 4–8. [CrossRef]
73. Birkeland, J. Net Positive Biophilic Urbanism. *Smart Sustain. Built Environ.* **2016**, *5*, 9–14. [CrossRef]
74. Santiago Fink, H. Human-Nature for Climate Action: Nature-Based Solutions for Urban Sustainability. *Sustainability* **2016**, *8*, 254. [CrossRef]
75. Söderlund, J.; Newman, P. Improving Mental Health in Prisons through Biophilic Design. *Prison J.* **2017**, *97*, 750–772. [CrossRef]
76. Beatley, T. Biophilic Cities and Healthy Societies. *Urban Plan.* **2017**, *2*, 1–4. [CrossRef]
77. Newman, P.; Beatley, T.; Boyer, H. Build Biophilic Urbanism in the City and Its Bioregion. In *Resilient Cities: Overcoming Fossil Fuel Dependence*; Island Press: Washington, DC, USA, 2017; pp. 127–153.
78. el-Baghdadi, O.; Desha, C. Conceptualising a Biophilic Services Model for Urban Areas. *Urban For. Urban Green.* **2017**, *27*, 399–408. [CrossRef]
79. Yin, J.; Zhu, S.; MacNaughton, P.; Allen, J.; Spengler, J. Physiological and Cognitive Performance of Exposure to Biophilic Indoor Environment. *Build. Environ.* **2018**, *132*, 255–262. [CrossRef]
80. Totaforti, S. Applying the Benefits of Biophilic Theory to Hospital Design. *City Territ. Arch.* **2018**, *5*, 1–9. [CrossRef]
81. Arvay, C. *The Biophilia Effect: A Scientific and Spiritual Exploration of the Healing Bond between Humans and Nature*; Sounds True: Boulder, CO, USA, 2018.
82. McDonald, R.; Beatley, T.; Elmqvist, T. The Green Soul of the Concrete Jungle: The Urban Century, the Urban Psychological Penalty, and the Role of Nature. *Sustain. Earth* **2018**, *1*, 3. [CrossRef]
83. Berto, R.; Barbiero, G.; Barbiero, P.; Senes, G. An Individual's Connection to Nature Can Affect Perceived Restorativeness of Natural Environments: Some Observations about Biophilia. *Behav. Sci.* **2018**, *8*, 34. [CrossRef] [PubMed]
84. Meltzer, N.; Bobilya, A.; Faircloth, W.; MItten, D.; Chandler, R. The Effect of an Outdoor Orientation Program on Participants' Biophilic Expressions. *J. Outdoor Environ. Educ.* **2018**, *21*, 187–205. [CrossRef]
85. Ayuso Sanchez, J.; Ikaga, T.; Vega Sanchez, S. Quantitative Improvement in Workplace Performance through Biophilic Design: A Pilot Experiment Case Study. *Energy Build.* **2018**, *177*, 316–328. [CrossRef]
86. Salingaros, N. The Biophilic Healing Index Predicts Effects of the Built Environment on Our Wellbeing. *J. Biourbanism* **2019**, *8*, 13–34.

87. El Messeidy, R. Application of Biophilic Patterns in Health Care Environments to Enhance Healing. *Eng. Res. J.* **2019**, *163*, 130–143. [CrossRef]
88. Parsaee, M.; Demers, C.; Hébert, M.; Lalonde, J.; Potvin, A. A Photobiological Approach to Biophilic Design in Extreme Climates. *Build. Environ.* **2019**, *154*, 211–226. [CrossRef]
89. Marselle, M. Theoretical Foundations of Biodiversity and Mental Wellbeing Relationships. In *Biodiversity and Health in the Face of Climate Change*; Springer: Cham, Switzerland, 2019; pp. 133–158.
90. Abdelaal, M. Biophilic Campus: An Emerging Planning Approach for a Sustainable Innovation-Conducive University. *J. Clean. Prod.* **2019**, *215*, 1445–1456. [CrossRef]
91. McGee, B.; Park, N.; Portillo, M.; Bosch, S.; Swisher, M. Diy Biophilia: Development of the Biophilic Interior Design Matrix as a Design Tool. *J. Inter. Des.* **2019**, *44*, 201–221. [CrossRef]
92. Africa, J.; Heerwagen, J.; Loftness, V.; Balagtas, C. Biophilic Design and Climate Change: Performance Parameters for Health. *Perspective* **2019**, *5*, 28. [CrossRef]
93. Aye, E.; Hackett, D.; Pozzuoli, C. The Intersection of Biophilia and Engineering in Creating Sustainable, Healthy and Structurally Sound Built Environment. In *WIT Transactions on Ecology and the Environment*; WIT Press: Southampton, UK, 2019; Volume 217, pp. 663–673.
94. Zari, M. Understanding and Designing Nature Experiences in Cities: A Framework for Biophilic Urbanism. *Cities Health* **2019**, *7*, 1–12.
95. Wallmann-Sperlich, B.; Hoffmann, S.; Salditt, A.; Bipp, T.; Froboese, I. Moving to an "Active" Biophilic Designed Office Workplace: A Pilot Study about the Effects on Sitting Time and Sitting Habits of Office-Based Workers. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1559. [CrossRef] [PubMed]
96. Xue, F.; Gou, Z.; Lau, S.; Lau, S.; Chung, K.; Zhang, J. From Biophilic Design to Biophilic Urbanism: Stakeholders' Perspectives. *J. Clean. Prod.* **2019**, *211*, 1444–1452. [CrossRef]
97. Emamjomeh, A.; Zhu, Y.; Beck, M. The Potential of Applying Immersive Virtual Environment to Biophilic Building Design: A Pilot Study. *J. Build. Eng.* **2020**, *32*, 101481. [CrossRef]
98. Peters, T.; D'Penna, K. Biophilic Design for Restorative University Learning Environments: A Critical Review of Literature and Design Recommendations. *Sustainability* **2020**, *12*, 7064. [CrossRef]
99. Chang, C.; Cheng, G.; Nghiem, T.; Song, X.; Ying, R.; Richards, D.; Roman Carrasco, L. Social Media, Nature, and Life Satisfaction: Global Evidence of the Biophilia Hypothesis. *Sci. Rep.* **2020**, *10*, 4125. [CrossRef]
100. Jaszczak, A.; Kristianova, K.; Wasilewska, O.; Bojović, D. Concepts of "Biophilia" and "Livability" in the Context of Social Perceprion of Public Space in the Cities. *Space Form* **2020**, *42*, 133–146.
101. Totaforti, S. Emerging Biophilic Urbanism: The Value of the Human–Nature Relationship in the Urban Space. *Sustainability* **2020**, *12*, 5487. [CrossRef]
102. Daniels, P.; Baghadadi, O.; Desha, C.; Matthews, T. Evaluating Net Community Benefits of Integrating Nature within Cities. *Sustain. Earth* **2020**, *3*, 12. [CrossRef]
103. Cabanek, A.; Zingoni de Baro, M.; Newman, P. Biophilic Streets: A Design Framework for Creating Multiple Urban Benefits. *Sustain. Earth* **2020**, *3*, 7. [CrossRef]
104. O'Regan, A.; Hunter, R.; Nyhan, M. "Biophilic Cities": Quantifying the Impact of Google Street View-Derived Greenspace Exposures on Socioeconomic Factors and Self-Reported Health. *Environ. Sci. Technol.* **2021**, *55*, 9063–9073. [CrossRef]
105. Verzwyvelt, L.; McNamara, A.; Xu, X.; Stubbins, R. Effects of Virtual Reality v. Biophilic Environments on Pain and Distress in Oncology Patients: A Case-crossover Pilot Study. *Sci. Rep.* **2021**, *11*, 20196. [CrossRef] [PubMed]
106. Mollazadeh, M.; Zhu, Y. Application of Virtual Environments for Biophilic Design: A Critical Review. *Buildings* **2021**, *11*, 148. [CrossRef]
107. Kavathekar, A.; Bantanur, S. An Evaluation of Performance and Wellbeing of Users through Biophilic Indicators: A Review. *Int. J. Archit. Eng. Constr.* **2021**, *10*, 22021002.
108. Aristizabal, S.; Byun, K.; Porter, P.; Clements, N.; Campanella, C. Biophilic Office Design: Exploring the Impact of a Multisensory Approach on Human Well-Being. *J. Environ. Psychol.* **2021**, *77*, 101682. [CrossRef]
109. Hähn, N.; Essahb, E.; Blanusaa, T. Biophilic Design and Office Planting: A Case Study of Effects on Perceived Health, Well-Being and Performance Metrics in the Workplace. *Intell. Build. Int.* **2021**, *13*, 241–260. [CrossRef]
110. Sayuti, A.; Ayn, N.; Bonollo, E.; Montana-Hoyosz, C. Emotional Responses, Perceptions, and Preferences toward Furniture Design Based on Living Organisms. *Int. J. Des. Objects* **2021**, *15*, 1–20. [CrossRef]
111. Carter, V.; Henríquez, C. Biophilic Institutions and Governance: Biophilic Urbanism Initiatives (BUIs) Fostering Green Urban Features in Emerging and Developing Cities. In *Studies in Efficient Environmental Design & City Planning*; Springer: Cham, Switzerland, 2021; pp. 126–128.
112. Lee, S.; Kim, Y. A Framework of Biophilic Urbanism for Mproving Climate Change Adaptability in Urban Environments. *Urban For. Urban Green.* **2021**, *61*, 127104. [CrossRef]
113. Thomson, G.; Newman, P. Green Infrastructure and Biophilic Urbanism as Tools for Integrating Resource Efficient and Ecological Cities. *Urban Plan.* **2021**, *6*, 75–88. [CrossRef]
114. Novosadová, L.; Knaap, W. The Role of Biophilic Agents in Building a Green Resilient City: The Case of Birmingham. *Sustainability* **2021**, *13*, 5033. [CrossRef]

115. Huntsman, D.; Bulaj, G. Healthy Dwelling: Design of Biophilic Interior Environments Fostering Self-Care Practices for People Living with Migraines, Chronic Pain, and Depression. *Int. J. Environ. Res. Public. Health* **2022**, *19*, 2248. [CrossRef] [PubMed]
116. Schiebel, T.; Gallinat, J.; Kühn, S. Testing the Biophilia Theory: Automatic Approach Tendencies towards Nature. *J. Environ. Psychol.* **2022**, *79*, 101725. [CrossRef]
117. Zhu, B.; Zhou, Y.; Weng, Q.; Luo, W.; He, X. Effects of Biophilic Virtual Reality on Cognitive Function of Patients Undergoing Laparoscopic Surgery: Study Protocol for a Sham Randomised Controlled Trial. *BMJ Open* **2022**, *12*, e052769. [CrossRef] [PubMed]
118. Lei, Q.; Lau, S.; Yuan, C.; Qi, Y. Post-Occupancy Evaluation of the Biophilic Design in the Workplace for Health and Wellbeing. *Buildings* **2022**, *12*, 417. [CrossRef]
119. Boğa, M.; Turan, G.; Çetinkaya, T. Biophilic Dimensions of Products and Their Effects on User Preferences. *AZ ITU J. Fac. Archit.* **2022**, *19*, 353–369.
120. Khozaei, F.; Carbon, C.; Hosseini Nia, M.; Kim, M. Preferences for Hotels with Biophilic Design Attributes in the Post-COVID-19 Era. *Buildings* **2022**, *12*, 427. [CrossRef]
121. Vileniske, I.; Daugelaite, A.; Viliunas, G. Classification of Biophilic Buildings as Sustainable Environments. *Buildings* **2022**, *12*, 1542. [CrossRef]
122. Lee, E.; Park, S. Biophilic Experience-Based Residential Hybrid Framework. *Environ. Res Public Health* **2022**, *19*, 8512. [CrossRef]
123. Nitu, M.; Gocer, O.; Wijesooriya, N.; Vijapur, D.; Candido, C. A Biophilic Design Approach for Improved Energy Performance in Retrofitting Residential Projects. *Sustainability* **2022**, *14*, 3776. [CrossRef]
124. Alaskary, A.; Alrobaee, T. Identifying and Measuring Biophilic Planning Indicators in Riverside Neighborhoods. *Civ. Eng. J.* **2022**, *8*, 33–44. [CrossRef]
125. Afify, R.; Dorra, M.; Aboubakr, D.; Shawket, I. Smart Biophilic Framework to Improve Productivity of Existing Office Buildings in Egypt. *Civ. Eng. Archit.* **2022**, *10*, 1931–1947. [CrossRef]
126. Schnell, S.; Brinkerhoff, D. Replicability and Scaling Up. In *International Encyclopedia of Civil Society*; Springer: New York, NY, USA, 2010; pp. 1312–1318.
127. Carter, S.; Currie-Alder, B. Scaling-up Natural Resource Management: Insights from Research in Latin America. *Dev. Pract.* **2006**, *16*, 128–140. [CrossRef]