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The Biophilic School: A Critical Synthesis of Evidence-Based Systematic Literature Reviews

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Abstract: Biophilic design emphasises human connections to nature to enhance health and well-being. In health and medical environments, the biophilic design hypothesis suggests improved healing and health outcomes when patients have a connection to nature. Emerging evidence indicates that if teachers and students experience a greater sense of health and well-being in the campus environment, they are likely to have better teaching and learning outcomes. To understand this at a deep level, a critical synthesis and analysis of some fifty systematic reviews outlines the significant emerging body of evidence in support of this approach. Systematic reviews are a fundamental basis for new research to be framed in the context of existing research findings within the evidence-based research methodology. Key outcomes of this critical synthesis review are that there is compelling evidence of some 70 health and well-being factors being improved though biophilic design. Also, organising an agreed taxonomy of biophilic design and health and well-being elements at a granular level would assist in simplifying and compiling the evidence of the benefits of such an approach to inform school funding, planning, design and operations authorities.

Keywords: biophilic; school; design; health; well-being; evidence-based; systematic literature review

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1. Introduction—Well-Being, Health and the Environment

The connection of health and wellbeing to nature has been increasingly studied in health and hospital planning and design over the past two decades [1,2]. Only recently, however, has such an approach been applied to school planning and design [3].

In undertaking this extensive synthesis and analysis of ss (systematic literature reviews), it became apparent that there is a need to reflect on the lineage of biophilic developments since Fromm [4] framed the biophilia hypothesis concept. In 'The Anatomy of Human Destructiveness', Fromm despaired of humankind's treatment and relative ignorance of the critical role nature plays in our lives and in the current epoch known as the Anthropocene. The biophilic hypothesis was developed further by Wilson [5], and subsequently by Kellert and Wilson [2], and more recently by Kellert [6] and Kellert and Calabrese [7]. Such an approach in school planning and design has had some limited exposure [8], and this study refreshes that approach and takes a much stronger account of a human-centred focus on school design through an evidence-based biophilic planning and design paradigm shift.

The past decade or so has seen a significant focus on health and well-being, as illustrated by the Australian Government's Department of Health and various other State government departments across Australia [9]. This study examined 'Health and the Environment: a Compilation of the Evidence'. The links between public health and the environment are also becoming subjects for significant research output, as seen in the RMIT University Healthy Liveable Cities Laboratory [10]. Recently, the South Australian Government has named its health organisation the Department for Health and Wellbeing.

2. Evidence-Based Health and Education Environments Planning and Design

In terms of evidence-based health planning and design, a milestone was achieved when a team of researchers led by Ulrich conducted a systematic review of all the evidence

related to the rate of healing of patients connected with the quality of the hospital physical environment [1]. A team of researchers produced a seminal paper analysing some 223 peer-reviewed papers on the topic demonstrating the connection between positive health outcomes with exposure to nature. This also connects closely with the International WELL Building Institute [11] which focusses on design for well-being.

Designing schools for health and well-being using the concept of 'flourishing', salutogenic [12] and eudaemonic design [13] are illustrated in Figure 1. Flourishing is a cross-disciplinary focus linking a wide range of factors, as illustrated in Figure 2 [14]. All these factors should be considered in school salutogenic and biophilic planning and design processes.

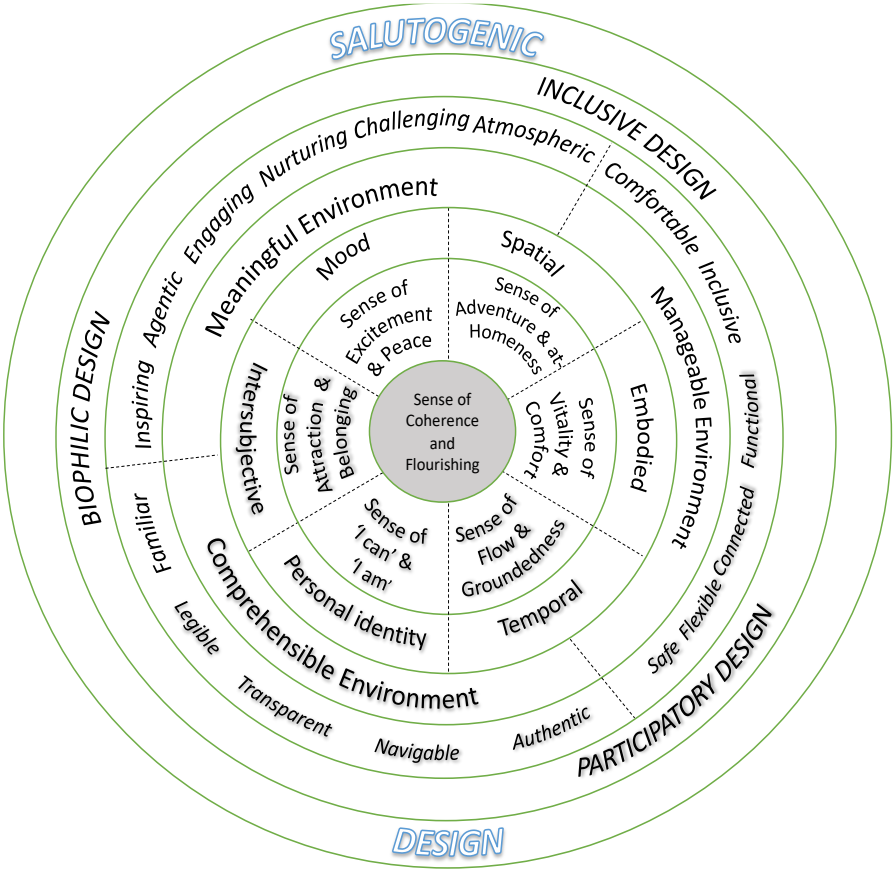

Figure 1. Salutogenic design framework for well-being as flourishing [13].

Biophilic design elements are covered in the literature and case studies but are organised—and to some extent simplified—in different ways by various authors such as Kellert and Calabrese [7] with 24 elements, Browning [15] with 14 elements and Lei [16] with 9 elements. These can be compared with the ever-evolving WELL Building Standard [11] and the World Green Building Council [17]. The interconnections and relationships with all five approaches can be seen in Figure 3.

The key simplified emerging themes included psychological; neurodiverse; physical; performance; emotional; health and well-being; and biophilic features. The search resulted in repeated examples of the impact of the environment on various aspects of health and well-being. For example, cognitive appeared in 16 articles, restorative in 13 articles and so on. These themes and the elements within each theme are summarised in Table 1.

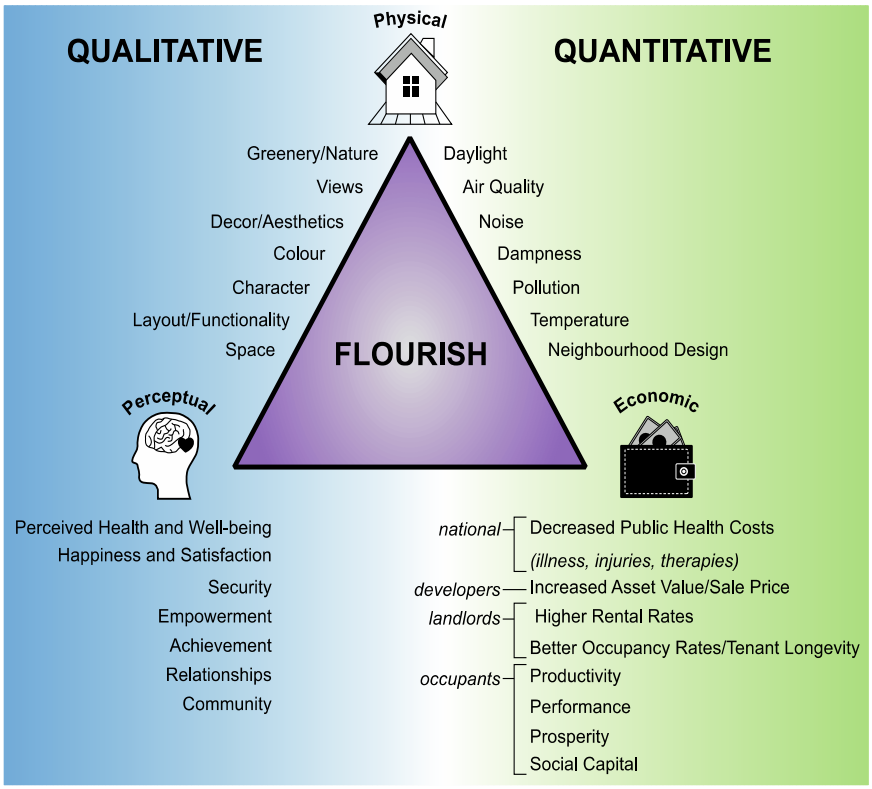

Figure 2. Flourish Model [14].

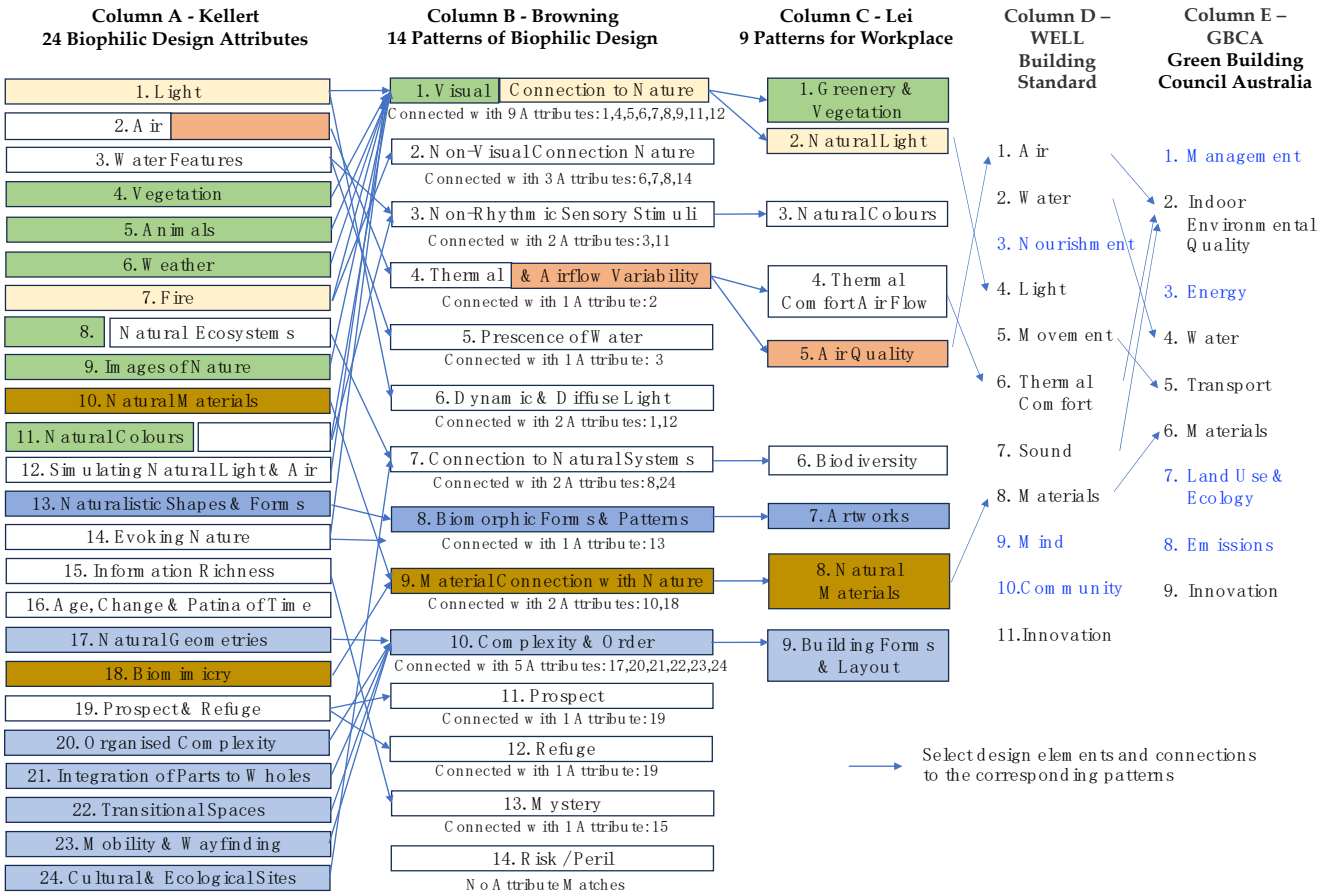

Figure 3. Just some of the biophilic models on offer [7,11,15–17].

Table 1. Categories of Key Abstract Words searched in shortlisted reviewed articles (generated by author).

Impact on Health and Well-Being	Elements in this Category in First Scoping Review
Cognitive, Psychological and Mental	Sensory; Attention Restoration Theory (ART); Stimulation; Psychiatric; Disorders; Cortisol; Sensing; Anxiety; Consciousness; Cognitive; Mental; Behavioural; Psychological; Innate
Performance and Intellectual	Performance; Attentional Performance; Desire; Success
Physical and Physiological	Restorative; Stress; Comfort; Proximity
Emotional and Mood	Identity; Affect; Mood; Connectedness; Perspective; Personal growth
Health, Well-being, Social, Behavioural and Developmental	Therapeutic; Flourish; Fatigue; Trauma; Healing; Health; Well-being; Electroencephalography (EEG); Holistic; Safety; Eudaimonic Well-being; Hedonic Well-being; Morbidity; Healthy; Literacy (health)
Neuroarchitecture and Neurodiverse	Neuroeducation; Neurodiverse; Neuroscience; Neuroarchitecture; Spectrum; Autism; Autism Spectrum Disorder (ASD); Functioning; Disability
Biophilic Features	Biophilic Quality Index (BQI); Nature; Trees; Indoor Air Quality; Greenspace; Empirical; Outdoor; Pollution; Green walls; Greenness; Ecosystem; Landscape; Interiors; Environments; Patterns; Meta-analysis; Bush Kinder; Ethnography; Systematic; Climate; Plants; Sustainability

3. Methods

This analysis and synthesis of multiple literature reviews first conducted a scoping literature review followed by an analysis of the evidence-based articles available from reputable peer-reviewed publishing venues. Systematic reviews are the highest form of scientific evidence with the methodology controlled through the PRISMA process (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). A synthesis of multiple systematic reviews analyses the 'eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings' [18]. Tools such as ROBIS (risk of bias) and AMSTAR-2 (methodological quality) are used to filter the data.

Some 1250 articles were sourced from venues as outlined in the PRISMA diagram in Figure 4 using the key words 'school; university; campus; health and wellbeing and biophilic planning and design' over five years. The 1250 articles were screened and then shortlisted as per the PRISMA process. That scoping literature review resulted in the shortlisting of 183 peer-reviewed journal articles and book chapters on biophilia in schools. This was then reduced to 67 articles which, collectively—when the Abstracts were searched for keywords—resulted in approximately 70 keywords.

Systematic literature reviews are a form of 'expert elicitation' [19]. This approach operates in a cross-disciplinary fashion and assists in aligning concepts, language, and evaluation methods without being focussed on any pre-determined paradigm. In short, if many experts can agree on a particular concept—especially in a qualitative narrative way—then the concept may be seen as being valid. Within the final 67 articles were 47 systematic literature reviews plus several related studies of the impact of nature on health and well-being which included workplaces and several clinical settings. There is increasing associated evidence within these sectors which may reflect or relate to findings in the school as a workplace. Having analysed all the final selected SLRs and additional relevant articles, it was decided to settle on the following themes: (1) psychological, cognitive and academic performance; (2) child development, early learning and forest schools; (3) greenspace and outdoors; (4) neuroarchitecture and neurodiversity; (5) higher education sector; (6) general health and well-being; and finally, (7) residential, clinical, health and workplace. These all have implications as an evidence base for supporting biophilic school design for health and well-being.

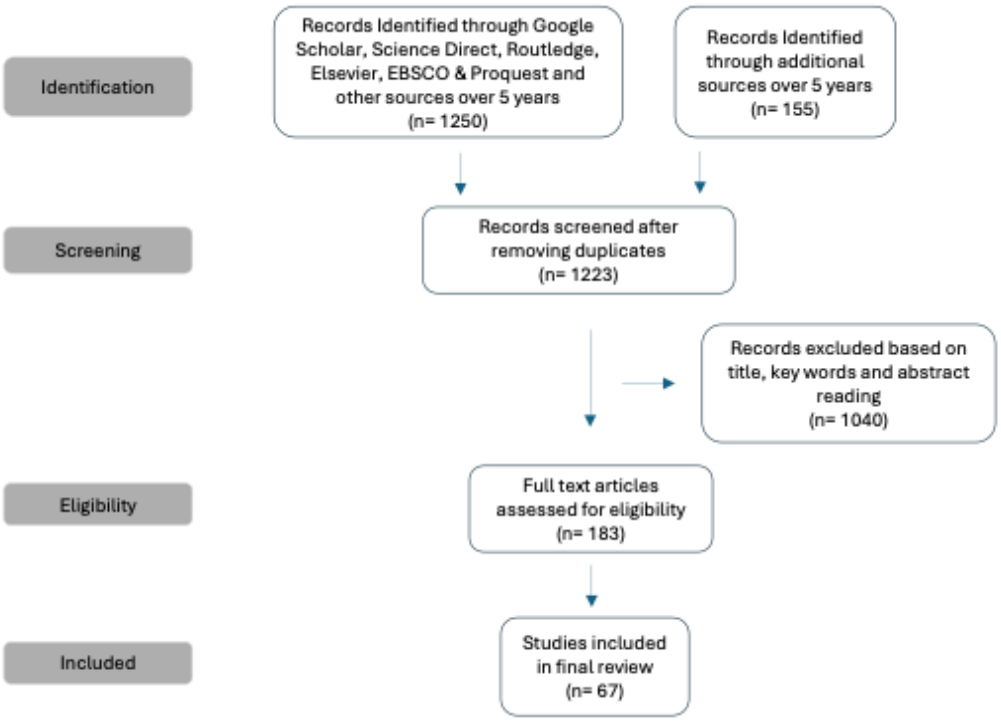

Figure 4. PRISMA flowchart.

4. A Critical Synthesis of the Systematic Literature Reviews

Note that all the references within each of the systematic literature reviews are not individually cited as it would make this paper too long. However, sources of any statements hereunder can be found within those individual systematic reviews that have been cited.

4.1. Psychological, Cognitive and Academic Performance

Some of the highlights in this category include improved cognitive development if the school has increased tree canopy [3]. Blood pressure and stress are also reduced in biophilic environments, and learning outcomes improve with greater natural light [20], which is also associated with increased physical activity, subjective well-being, improved alertness, faster cognitive speed, and better concentration. Green environments adjacent to campuses were also found to improve academic performances [20].

Views and sounds of water assist in restorative effects [21], and this was physiological rather than psychological. Indoor plants can also result in improved performance, with various options offering alternative benefits [22]. Views of nature provided varying benefits depending on the type of nature in view. In this context, attention restoration theory (ART) suggested that in some cases artificial images can be more beneficial. Natural materials can also be effective in restoration, although research is limited. The use of timber is perhaps considered to be the most effective.

Stress reduction and mental restoration are likely to improve with connection to nature, whilst students exhibit significantly improved performance on attention test and stress recovery [22]. Connection to nature also sees improvements in other areas including creativity, depression, PTSD, attention deficit recovery, happiness and life satisfaction, enhanced memory retention, dementia, productivity, and self-esteem.

Attention restoration theory [23] and the influence of nature on cognition and stress recovery [24] through a psycho-physiological engagement with nature is used to argue that nature improves academic performance [25]. Access to nature improves concentration over longer periods of time, and the immersive effect improves focus and energy levels. However, only two studies focussed on schools specifically. One of these used data from the Twin Cities Metropolitan Area (TCMA) of Minnesota, which has data on educational

performance modified for social and economic disadvantages. It also has data on vegetation coverage and, after discarding schools that were confounding, resulted in a sample size of 222 schools with 3rd grade students being scored using the Minnesota Comprehensive Assessment of the Department of Education for reading and mathematics. Both measures showed improvements after regression analysis.

Nature in the study environment was analysed in a systematic literature review by van den Bogerd [26]. This study developed a three-tiered nature impact arrangement for evaluation: (1) reducing harm (mitigation); (2) restoring capacities (restoration); and (3) building capacities (instoration). Note that 'instoration' implies an active engagement with nature, whereas restoration can be 'passive' engagement. The reviews included 14 studies in secondary schools and 23 studies in universities, with campus green space examined together with the impact of indoor plants. No differences were found between the two educational sectors. Campus green space was found to improve restoration and general well-being and quality of life.

Greenspace was also found to reduce temperature on campus grounds. The studies also differentiated between passive and active exposure to nature. Furthermore, inclusion of water and views improved the experience of indoor nature and related health measures. In some studies, there were issues in bias, confounding factors and baseline differences, and more longitudinal and controlled evaluations were recommended in future studies. The studies reviewed were European-focussed, and it was suggested that they would not necessarily directly translate to other countries.

Another systematic review [27] found that there is evidence to support that exposure to nature improved cognitive performance regarding selective attention, sustained attention and working memory, together with enhanced well-being, cognitive restoration, and stress reduction. Additional factors included improvements in emotional and behavioural issues around inattention and hyperactivity.

Testing included impulse control, processing speed, long-term memory and knowledge acquisition, selective attention, sustained/selective attention and working memory. Most of this work used passive nature attributes. They also noted that in establishing the quality of articles they used the EPHPP (Effective Public Health Practice Project) framework, which assesses six domains—selection bias, study design, confounders, blinding, data collection methods, withdrawals, and dropouts. The study also concluded that nature exposure type—passive or active—is critical in framing any research programme.

4.2. Child Development, Early Learning and Forest Schools

Whilst Adams and Savahl's [28] study focussed more on perceptions of and attitudes toward nature, there are some findings regarding active engagement with nature which can improve cognitive, physical, affective effects, and moral development. Articles included illustrated how nature is important in healthy child development, suggested subjective well-being, provided a buffer to life stress and cognitive functioning, and noted the variable impact that nature can have on cognitive styles. Nature exposure was also thought to mitigate ADHD symptoms.

Arola et al. [29] separated qualitative and quantitative articles. They found that nature connectedness showed a decrease in psychosomatic symptoms and increased self-satisfaction, positive mood, and social interaction. Other factors which showed improvement included reduced stress; increased happiness and joy; improved mindfulness and spirituality; greater competence, self-esteem and emotional well-being; enhanced social well-being and competence; and exhibited an overall heightened sense of physical well-being.

The measurement and categorization of natural environments is key to evaluation [30]. This particular study discriminated between outdoor spaces as 'natural environments' and indoor spaces as 'virtual environments' because of the built form of the latter. Various datasets were used in this study to measure natural environments. Regarding health outcomes, six categories were evaluated in the selected articles: academic achievement;

prevalence of doctor-diagnosed disorders; emotional and behavioural functioning; well-being; social functioning; and cognitive skills. Emotional and behavioural function included attention, interpersonal relationships and ADHD. Cognitive skills assessment used a test for memory performance and cognitive performance. All test tools used were listed across the six categories. Academic achievement was seen to improve if exposed to natural environments and doctor diagnoses were lower. Behavioural and emotional aspects were improved and there was also improvement in some aspects of memory.

Another related study long listed massive numbers of articles—some 37,159 references reduced to 65—with the final articles showing various improvements in a range of child development factors) [31]. The review is quite complex but does suggest strong improvements in nature play's impact on social skills, independent thought, lower behavioural problems, emotional development and well-being, cognitive development and cognitive play, creativity, imagination and dramatic play and self-regulation.

Regarding the psychological impact of nature on 6–12-year-olds, it has been suggested that there are more cross-sectional studies than longitudinal ones, with an equal number of observational (quantity and accessibility of green spaces) and experimental studies, but little work on blue/water impact [32]. In evaluating the quantity vs. quality of nature/green spaces, it was found that observational and quality studies can result in positive affective responses including joy, excitement and restoration. But some nature features can manifest stress, danger and threat feelings. Experimental studies showed that views of both nature and simulated nature had a positive impact on well-being, but that actual natural engagement had a higher impact. Active engagement in urban forest settings can improve psychological well-being, self-esteem and peer relationships. Overall, the systematic review revealed a positive impact on psychological well-being with increased engagement with nature.

An experimental study using the notion of personal comfort systems (PCS) is included here in large part because of this author's personal experience in schools regarding thermal comfort [33] The PCS model was used with 18 respondents in a controlled environmental room—airspeed, temperature, relative humidity and lighting were controlled—with the addition of being able to cool the headspace and extremities of individuals at a desk setting with various user controls. Fourteen temperature sensors were applied to the body. Various tasks were undertaken as specified within several professionally accepted frameworks.

Tasks included anti-cue, complex tasks, planning tasks, verbal ability, working memory and mental spatial manipulations. Measures included NASA-defined subjective perception of cognitive load task-induced physiological responses, arousal and alertness and interaction between tasks and performance. Outcomes included the finding that cooling the head (if ambient is over 25 °C) improved the anti-cue task and complex cognitive performance. Lower temperatures also increased task performance. Conversely, however, warming from a colder temperature did not affect complex cognitive performance.

Meng's systematic literature review of the indoor visual environment of children selected five environmental factors for analysis including: lighting, access to nature, window features, art and environmental aesthetics, and ergonomics in spatial settings [34]. It found that appropriate lighting and access to nature had the most evidence supporting benefits to children's health, with dynamic lighting responding to children's activities being the most beneficial.

A number of studies had some evidence of possible bias, which raised questions about the quality of the research methodologies. The lighting studies feature heavily in the United States, whilst the nature-restorative studies had a greater representation in Europe.

Russo [35] found that access to nature can elicit positive multiple childhood health outcomes, including decreased emotional and behavioural difficulties, higher academic achievement and improved overall mental well-being and cognitive development. Another survey of 145 schools in Scotland by Robertson et al. [36] saw 82% of respondents say that it is vital/essential that students should spend time outdoors regularly; 85% of schools say students use the outdoors every day; 47% said that students should visit woodland

regularly. Whilst only 30% of schools have woodland on their campus, 78% can access nearby woodland, with between 66% and 80% accessible by walking.

That said, only about 43% visit the nearby woodland site regularly. Schools ranked in importance the following benefits generally regarding access to nature as: Learning Opportunity (23%); Natural Resources (22%); Emotional Well-being (17%); Physical Activity (16%); Better Quality of Play (15%) and Better Behaviour (8%). There was strong interest in developing a forest kindergarten, with up to 68% of organisations wanting to do so 'as soon as possible'.

Forest schools provide excellent opportunities for deep research in the connection between nature and health and well-being [37]. Interaction patterns (IP) in 'wild natural' parks were used to develop a human–nature interaction model which was then used on two outdoor classrooms in a forest school located in an arboretum. After 35 weeks of filming interactions in six zones in the outdoor classrooms, these interactions were coded and analysed. From 1,851 interaction patterns, 25 were determined to be keystone patterns, with 8 of these being selected as indicative of bonding with 'wild' elements of nature. These included cohabitating with a wild animal, imitating animals, calling birds, leaning against a tree, lying on earth, being in solitude in nature actively, and being in solitude in nature.

Key findings included that in outdoor classrooms, active learning serves to strengthen child bones, muscles, hearts and lungs. It also improves coordination, balance, and posture and helps in sustaining a healthy weight. Moreover, it reduces illnesses including cancer and diabetes. Engaging with 'wild' nature suggests that students are in a relational connection with nature, rather than dominating nature.

4.3. Greenspace and Outdoors

Observational studies of the relationship between greenspace on mental health are instrumental in much of the work in this field, with 'blue space' making up 25% of studies [38]. Generally the quantity of greenspace was used in longitudinal studies exploring mental health and it was recommended that further research should also focus on the quality of greenspace. Studies were carried out in Europe, North America, Asia, Australia, New Zealand and South America, with the UK contributing 24% of all studies and Japan contributing 15% of experimental studies. Scale was a significant issue arising out of these studies, both in terms of the scale of nature and the scale of the study respondent numbers and their variable time spent in nature and greenspace.

Whilst both observational and experimental studies were studies, it was found that the experimental studies are viewed as more 'gold standard' than observational studies. The review could not establish a direct causal relationship between greenspace and mental health because of the variations between the scale and quality of greenspace, the variations in time spent in the space and the varying longitudinal nature of the studies. These factors need to be considered in future studies.

Conversely, a meta-analysis of prescribing a rehabilitation approach using nature-based interventions to improve the depression of community-based adults [39] found that an optimal dose of 12 weeks of gardening, green exercise and nature-based therapy can improve mental health problems in adults (perhaps more suited to senior secondary school in this context), including for those with pre-existing conditions. In particular, random controlled trials showed a reduction in symptoms of depressive mood. Forest bathing proved the most effective in this regard and reduced depressive mood symptoms. There was also a large decrease in anxiety symptoms, together with a large increase in positive affect. Gardening was seen to have a significant effect on physical activity over a year-long study with respondents who had serious mental illness.

A narrative synthesis study by Fernandez of 39 research articles focussing on 5- to 12-year-olds considered three factors: indoor environmental quality (IEQ); increasing student 'green time' by school greening; and more active travel to school [40]. The review suggested that the studies were not sufficiently robust to be considered useful. That said,

it did find that greening schools does influence cognition and physical activity, although behaviour was not considered to be affected at least in this study.

Another study used student academic performance as an indicator of cognitive abilities connected with or in close proximity to green spaces [41]. Three green indicators/metrics were used: (a) GIS/NDVI (Geographic Information System mapping technology and Normalised Difference Vegetation Index, a satellite indicator of green canopy density); (b) distance to green spaces (buffers of 500, 750 and 1000 metres around schools); and (c) the quantity of green spaces. Academic performance was sourced from Government Education databases. Whilst the study did find a relationship between the distance of greenspace and academic performance, the quantity of greenspace was a key factor which needs further consideration.

4.4. Neuro-Architecture and Neurodiversity

Neuroscience and architecture are becoming a significant feature of research focussing on the connections between the two. Neurodiversity is also of increasing importance for students with learning difficulties requiring much greater attention as to how the physical learning environment might impact on their capabilities.

Four aspects of well-being are the focus of one such systematic review—the physical (body); the intellectual (brain); the emotions; and the social (behaviours) [42]. The study used a descriptive thematic, narrative and critical analysis approach which produced a heuristic neuro-architectural model relating design characteristics with 'experimentally proven' physiological, psychological, cognitive and behavioural effects. The model relates these human factors to architectural designs ('unconscious' perceptions); physiology (human body functions); psychology (emotions and behaviour); and neuroscience (neurology, cognition, perception).

Various physiological measurement tools were used in differently designed environments, with both physical and virtual experiences. Few studies considered smells and dark colours, but natural materials such as wood led to lower heart rates and less sweating in both environments. The authors noted that physiological changes (both subconsciously and consciously) related to different architectural features altered blood flows to different parts of the brain. The resulting emotions were thought to modulate the brain activity in areas related to attention, memory, motivations, emotions (mood) and decision-making which all led to better psychology, well-being and restoration.

Another systematic review studied interior architectural designs and their impact on the autonomic nervous system (ANS) and/or the central nervous system (CNS) [43]. The study separated affect and emotion, with the former related to valence and arousal and the latter being defined in neurobiological terms as a complex reaction stimulus of cortical brain networks. Blood oxygenation was measured as an indication of neuronal stimulation. In addition, heart rate, blood pressure, breathing rate and galvanic skin responses were measured. The physical interiors were organised in a confined floor and ceiling space having four sides. Greater than four sides and curvilinear surfaces were considered to be semi-enclosed if there were solid partial barriers. Findings included that lower ceilings resulted in a lower judgement of beauty; linear geometries resulted in lower self-ratings for pleasure and arousal, with decreased anterior cingulate cortex activity. Furnished interiors had higher self-rated emotions related to presence and arousal according to the style of furniture, with increased heart rates. Depth in virtual environments increased the sense of presence, and wood (as materiality) reduced the impact on the ANS.

Cognitive judgements of architecture can also be a response to prior external experiences rather than internal emotions [44]. In this context, 'extrospective' and 'introspective' evaluations can be related to 'dissociable neural circuitry'. Five cognitive architectural judgements were considered, namely: complexity; organisation; modernity; naturalness; and beauty. These characteristics can affect the degree of physiological stimulation experienced. They can be uplifting or depressing, and these responses can predict long-term health measures including stress and depression. Vitality and valence (the latter mean-

ing whether the space is desirable or undesirable) are related to preference, liking and pleasantness. These affective responses relate to neural networks which regulate pleasure and emotion.

For example, 'hominess' ratings can be a result of culture, background and memories which may influence cognitive and sensory processes. There are two characteristics: emotional responses (of which eight are considered including: personalness, hominess, relaxation, comfort, stimulation, uplift, vitality and valence) and behavioural–emotional responses. The latter consist of measures of behaviour, movement and motivation, all of which may be linked to sensorimotor processes in the brain. Three behavioural–emotional responses are considered here including: interest, approachability, and exploration. These can all result in sensorimotor, cognitive and emotional responses.

All of these aesthetic/response measures in this case study are related to, and examined through, three key physical variables, namely: ceiling height; enclosure and curvature. The authors then construct a psychometric network analysis of elements. By a complex process—a little too complex and dense to describe in detail here—the authors then examine responses to three criteria with MRI (magnetic resonance imaging) brain scans namely: hominess; coherence; and fascination. They conclude that open spaces scored more highly. A high ceiling, openness and curvature are also considered to be more beautiful and are more likely to stimulate movement and exploration similar to the previous study [43].

Respondents also preferred greater affordances of visual prospect, and the preferences for high ceilings and curved interiors resulted in more active 'neural structures associated with visuospatial exploration and attention'. Certain visual features could also modulate psychological responses related to fascination. However, they 'suspect' that in some cases, these responses may be more related to extrospective rather than introspective forces. IT was suggested that the three spatial elements could possibly be linked to the 16 aesthetic/response measures in further MRI studies to see if these elements could be added to the abovementioned factors within the notion of flourishing.

Karakas considered the differences between 'theoretic' frameworks and experimental studies [45]. The experimental articles resulted in five themes as illustrated in Table 2. These themes all had associated neurological responses. Many—if not all—of these responses resonate with other systematic literature review findings in this synthesis overview.

Table 2. Relationships between spatial typologies and human responses (by author).

Spatial Theme/Activity	Human Response
Restorative and stress reduction affordance	Well-being, restorativeness and stress reduction
Aesthetic judgment and appreciation	Pleasure, familiarity, novelty, comfort and pleasantness
Pedestrian experience, navigation and wayfinding	Mediation, attention, anxiety, displeasure, positive and negative emotions, intense and mild, pleasant and unpleasant, directional behaviour, familiarity and fear
Visual engagement, visual attention and imageability	Visual attention, avoidant behaviour, conscious and unconscious attention, efficient, pretty, safe, pleasant, interesting
Phenomenological experiences, experiential intensity, user experience, multisensory experience and natural experience of architectural spaces	Relaxation, excitement, engagement, reduced stress, focus, interest, attention, appreciation, peace, beauty, connectedness, reduced anxiety, pleasure, motivation, pleasure and frustration

Colour and the perceived 'temperature of colour' are not covered to any great degree in the literature on biophilia [46]. This study has been included to provide some input to afford a more complete biophilic hypothesis. It investigates the effects of personal control of lighting on visual and thermal responses, together with affect and cognitive performance. Sixteen participants were tested with user control of colour-correlated temperature (CCT) of ceiling-mounted lighting, task lighting and computer screen lighting. Prior to this, respondents had a 24 hour-controlled environment, sleeping and eating pattern. Also, prior to the test, various sensors were applied to the individuals.

In the first 1.5 h session, the tasks were applied without any control of CCT. In the second session, respondents carried out cognitive tasks for one and a half hours but could use the CCT controls to vary the settings to their preferences during the first 10 min. They then carried out similar activities to the first trial, but with their own lighting settings. Findings were that thermal appraisal was not significantly affected by having CCT control. However, personal control of CCT improved visual acuity and also mitigated eyestrain, although it did not improve cognitive performance.

Whilst Parhizkar [47] focussed on office workers, findings in this sector can be relevant to schools in many ways. That study used a Flourishing Index (FI) to assess the well-being of office workers in relation to indoor environmental quality (IEQ). Note that 574 office workers located in 7 separate buildings were surveyed using a 5-point scale. The FI scores correlated with IEQ satisfaction, including noise, temperature and light. With higher CO2 and lower IEQ satisfaction, lower FI scores were related to reports of respiratory symptoms, shortness of breath, coughs and sore throats. The connection between CO2 and FI could be mediated by improved IEQ factors, but PM2.5 (particulate matter in microns, a key issue in Bangkok schools) directly affected FI ratings. The flourishing index rated happiness and life satisfaction, health, meaning in life, character strengths and social relationships.

Environmental psychology has also provided a rich vein of research on neuroarchitecture and biophilic design [48]. Joye argues that psycho-evolutionary development can be seen as a framework and can be used to track how humans have evolved in terms of their relationship with nature and its impact on cognition. This suggests that different environments can have differing impacts on our affective experience of those environments. Kaplan [23] and Ulrich [49] differ in that the former argues that we respond to information we receive in each setting, whereas the latter argues that we have an instinctive flight or fight response which dates back millennia (see below). The notion of affective valence supports the latter concept.

Regarding the neural origin of these affective states, some researchers attribute an important role to subcortical areas, especially the amygdala. Because these structures are also involved in modulating stress-related hormones, it provides an explanation of why certain types of settings have a different influence on autonomic stress responses [48].

In relation to the attention restoration theory (ART) discussed earlier, Joye compares Kaplan and Ulrich's interpretations. The former argues that ART is related to attentional capacities, whereas the latter believes it is related to stress, which can occur while attentional capacities may not be impeded. So, whilst the flight or fight reaction might be useful, it can still result in psychological and physiological stress. There are variations in these reactions, depending on the type of landscape being experienced, which Ulrich calls Structural Landscape Features. Biophilic design attempts to fold these structural landscape features into the building designs, so that the restorative effects can be experienced.

It is through this model that some of Browning's 14 elements are derived, such as prospect, refuge, mystery, curiosity, coherence and complexity [15]. Later developments on this idea have led to the transfer of fractal geometry from nature into architectural design features. Joye discusses the links between various natural fractal geometries, restoration and preferences, which Ulrich calls the affective value of fractals [24]. Joye describes various examples of the use of fractal architecture deploying repeated scales using gothic architecture and Hindu temples as examples.

Nature-based architecture implies that the building enters a dialogue with a specific set of human inborn affiliations. However, adherents of biophilic architecture should become aware that their work also has to relate to or become embedded in a social, historical, ecological and individual context [48].

Another neuro-architectural study notes that in the developed world, people spend as much as 90% of their time indoors and, in some cases—particularly in the UK, for example—as much as 95%, meaning that connection to nature is minimal [50]. Valentine asserts that physiological stress can be linked to various diseases including cardiovascular, neurodegenerative, autoimmune fatty liver disease, chronic kidney disease and cancer.

This systematic review found that physical design attributes which can impact affect and preference include curvature, enclosure and proportion, as discussed earlier. Valentine suggests that clinical biomarkers can be used to measure the impact of these features on stress.

These markers were measured using electroencephalography (EEG); functional magnetic resonance imaging (fMRI); heart rate variability (HRV); galvanic skin responses (GSR); pupil dilation; and salivary cortisol. Three forms of architecture were used—virtual reality (VR); 2D images; and physical reality, i.e., actual buildings. The three abovementioned forms were all tested, and the responses were measured. Some of the examples used classrooms, but the author suggests that the variety of spaces used made it a complex task to compare results and suggested that a more standardised research methodology model should be developed. The ultimate findings are that the biomarkers are a valid way of measuring responses, and that the three spatial typologies—with all their complex variations—can influence these biomarkers.

4.5. Higher Education Sector

Several reviews focussed on university campuses. Abdelaal found a connection between nature and cognition, cognitive performance, reduced mental fatigue, improved productivity and attention, academic performance, attentiveness, improved concentration and memory [51]. The study categorized three types of restoration: (a) physical and psychological stress reduction (five references); (b) psychological self-esteem, mood, anxiety, attitude, and happiness (seven references); (c) social interaction and spiritual well-being (six references). The study looked at two types of biophilic interaction—degree of interaction and interaction features and patterns. The health and well-being impacts were measured in four categories—physical/physiological, psychological, cognitive and social/spiritual. In terms of retrofitting biophilic features into campuses to improve health and well-being, the author notes several barriers including the existing spatial configuration of campuses and buildings of the past which makes it difficult to retrofit biophilic designs.

University libraries are learning spaces which have had little research carried out in the context of the health and well-being of students and staff. Now Khair's systematic review has found benefits of biophilic design on the performance of academic, intellectual and cognitive tasks, student productivity, creativity and physical activity as well as nourishing intellectual curiosity and innovation [52]. Views of nature also benefit mental breaks (restorative), improved attention function and learning. Key biophilic factors were found to be spatial proportions, natural ventilation, indoor plants and daylight. There was also a calming effect and improved stimulation, wellness and performance.

Students also appeared to have improved emotional, psychological and physiological benefits and were happier regardless of demographics. Relaxation is improved, as is self-esteem, and there were overall improved feelings due to improved blood pressure and heart rate. Visual, auditory and olfactory stimulation all appear to be improved, with floral fragrances thought to enhance better moods. Students also appeared to prefer to study in 'refuge' spaces with 'prospect' views and to feel privacy, security and excitement. Natural light is preferred, but artificial light designed to suit the task and spatial typology were also critical to comfort. Study spaces next to windows were preferred. Vegetation was seen to be an effective influence on microclimate and the moderation of noise levels.

Peters' review of university campuses supported many of the abovementioned findings including that lighting systems serve to make learning spaces attractive and pleasant and enhance the sense of spaciousness, assist in delineating settings, stimulate learning and show better learning behaviour, whilst students in areas of natural light perform better than those in artificial light [53]. In addition, this study noted that a sense of place and place attachment increased, including an enhanced sense of happiness that was evident with biophilic design. Nature connectedness was also reported by students as fostering innovative and holistic thinkers. The preference for 'refuge' study space together with 'prospect' was also supported. IEQ improved student productivity, with adjacency to

windows the most effective. Connections to nature also reduced depression and ADHD symptoms. The systematic review also provides guidelines for biophilic design interventions to support these abovementioned enhancements to student experiences and their health and well-being.

Saarani's study of university students focussed on emotion, health and well-being and cognition, with each category of these elements being rated on the numbers of mentions in the review articles [54]. The biophilic impact on emotion ranked highest on attitude, with psychological restoration and positive emotional responses rated next. Self-esteem, feelings of comfort and reduced anger are also indicated as improving. Reduced mental fatigue, illness and anxiety featured in the health and well-being category. Cognitive performance was found to have the most impact in relation to biophilic effects, with improved productivity, commitment and ability to perform, and a positive impact on concentration, memory, mental engagement and attention being the most improved through biophilic design. Additional affective factors which are enhanced include cognitive performance, satisfaction and confidence levels. At a more reduced rate of improvement lie academic performance, inspiration and motivation, social interaction and creativity.

Campus greening is also an area receiving more attention in biophilic research. van den Bogerd's review examined the effects of campus green space on students' well-being and on students' academic outcomes [55]. A higher quality of life was suggested in four studies where there was greater access to—and higher availability of—campus greenspace. In addition, there was seen to be better general health (these two were seen as medium risks). Regarding green space and student academic outcomes, one moderate risk study found that tree canopy within a one-mile buffer was associated with higher test scores. One high-risk study noted that campus green space improved secondary students' knowledge retention after an outdoor classroom activity. Yilmaz and Ayten [56] provide an excellent analysis and case study as to how Browning's [15] fourteen biophilic patterns can be applied to a university campus.

4.6. General Health and Well-Being

There are now many studies on the relationship of nature to health and well-being outside of the educational sector, and the systematic reviews of these examples are useful to compare and add to the school-based studies. One such study around healing landscapes saw architectural students taking photos of the views out of their own homes to discuss in class [57]. The resulting systematic review explored the concept of the 'biophilic hierarchy of needs'—or BHON —which is adapted from Maslow's hierarchy of needs [58,59]. The human impact measures used groupings around physiological, psychological, cognitive and well-being outcomes.

Zhang's integrated narrative review explored the effect of nature on physical and psychological needs [60]. It notes that people find different benefits from exposure to nature and can also gain benefits from very short exposure in some cases. The authors developed a 'new heuristic point of view' on the necessity of these connections. In the case of physical health, they focussed on cardiovascular disease; immunity; synthetic nervous system function; and sleep quality. For psychological well-being, they reviewed mental health; attention; mood; stress; and cognitive development. These were qualified and measured against nature exposure and nature connectedness. They conclude that the varied nature of exposure and connection to nature and the varied benefits require a heuristic or bespoke approach to optimise those benefits.

4.7. Residential, Clinical, Health and Workplace

As noted earlier, other sectors may have relevance to biophilic school design in adding to an increasing evidence base for this practice. It was suggested that there was little evidence concerning cardiovascular disease (CD) and related death rates and connections to nature, and so it was decided to conduct a systematic review focussing on this aspect [61]. Gascon's final 12 studies were heterogenous in design, with similar population sizes, green

space evaluation and covariate data. It found conclusive evidence that CD mortality was reduced in areas of higher-density residential green spaces. Gascon suggested that further studies might account for socioeconomic status and that green spaces need to have a consistent definition regarding density and typology.

The workplace is considered to have little research on the impact of nature on workers (contrary to another abovementioned study), and it is suggested that what exists is limited and scattered [62]. Goncalves' systematic review considered outdoor and indoor nature exposure, and this exposure was related to well-being, motivation, job satisfaction and work performance. Of the 16 shortlisted studies, 9 were based on simulated nature exposure in the indoor spaces, and these simulated exposures also had positive effects on the employee factors measured. Likewise, the outdoor spaces also had positive effects. It was suggested that 12% green coverage indoors was an optimal measure to positively impact both psychological and physiological outcomes, including productivity. In quoting Lei [16] Gascon noted that over 12% up to 20% coverage could negatively affect positive change on physiological brain activities.

In a similar vein, Sadick identified the lack of connection between sustainable design and the health and well-being of office workers [63]. To enhance the missing social sustainability of the human–nature interface, this study also sought to understand how nature exposure in the indoor and outdoor environments could enhance workers' well-being in five categories—restoration; motivation; stress reduction; health; and stress coping strategies—which were considered integral to three areas of study: physical, psychological and cognitive. Nature exposure was observed to be beneficial with all five categories, although the three most impacted included stress reduction, restoration and coping.

The experience of nature was seen as breaking the stress cycle of work activities. The study found that indoor exposure is less effective for restoration and stress reduction due to the proximity of the sources of stressors, although it is essential to have indoor interventions to improve motivation and health to sustain cognitive performance. It emphasised the requirement to have a diverse range of nature experiences as people respond to differing exposures in different ways. That is, a 'once size fits all' is not the preferred approach. The study arrived at a network mapping diagram to illustrate the respective pathways of nature exposure and the resulting positive outcomes on the workers.

Tekin's research in a clinical hospital environment noted the lack of an agreed standardised guidance for the benefits of biophilic design on clinical users [64]. In asking the question 'which biophilic criteria are most critical in a clinical therapeutic environment and how do they inform design?', the study found that three distinctive user groups had specific preferences for the nature exposure experience: outpatients (fresh air, light–daylight, thermal comfort, welcoming and relaxing); inpatients (feeling relaxed and comfortable, prospect refuge, security and protection, light–daylight, view); and staff (privacy refuge, quietness).

Many of the studies reviewed were from departments of medicine, health, design and environmental analysis, architecture, forestry and natural resources, clinical, neuro- and development psychology, as can be seen in Tekin's doctorate on the topic [65]. That study found that 'it was confirmed that emotional, mental and spiritual health issues are typically disregarded while the main foci are physical treatment and cost'.

5. Key Findings and Discussion

Notwithstanding the rapidly emerging body of literature on how nature can impact health and well-being, LeFosse noted that despite biophilia having had centuries of human–nature interaction research and design (to whit Indigenous, Arabic, Moorish, Egyptian, Roman, Etruscan, et al.), biophilia still remains an emerging field of research [66]. This study covered 60 years of literature using a 'three-metric' systematic literature review approach consisting of quality, quantity and application. As one of the few systematic literature reviews to encounter biophilic urbanism, it argues for a greater emphasis on a broader and longer-term scale to promote a paradigm shift in city planning. It calls for new concepts of bioregional systems where 'nature plays a key role in ensuring ecological

services and citizens' well-being'. It concluded that biophilia (theory), biophilic design (practice) and biophilic urbanism comprise a triad consisting of disciplinary, metric and spatial dimensions which can form a notion of biophilic upscaling, which is suggested as the best way forward.

Regarding 'biophilic architecture', this also implies that fractal architecture should also respond to critical regionalism, where the terroir, cultural history, vernacular, micro-climate, topography, geology, soil and native vegetation should all be considered as part of a fractal ecosystem [8]. In short, designers should be cognisant of the full environmental ecosystem in planning their buildings, with a view to engaging with—indeed enhancing—biodiversity through the 'nature positive' concept [67].

In this context, Wijesooriya argues that environmentally sustainable design (ESD) does not focus sufficiently on human interactions with the built form [68]. ESD focuses more on the building rather than the approach of 'human centred design'. The WELL certified and biophilic design approaches seek to redress this disparity by covering both ESD and the biophilic effect. Wijesooriya suggests that there are excellent opportunities to capitalise on designing for improved outcomes of cognitive, behavioural, health and well-being and emotional impacts.

Independent reviewers of this manuscript suggested that the findings be presented in a tabular format, as illustrated in Vella-Brodrick's study [27]. This is a challenging task because of the complexity of both the biophilic element typologies—ranging from 9 to 24 in Figure 3—and the range of human responses (numbering seventy) to these biophilic elements, as illustrated in Table 3.

After analysing, synthesising and critiquing the SLRs, it was decided to condense the many biophilic elements named in those SLRs to the following 12 elements, namely: (1) connection to nature; (2) biophilic features; (3) natural light and control; (4) views of nature and virtual; (5) natural materials, especially timber; (6) indoor environment quality; (7) campus green space; (8) green adjacent to campus; (9) increased tree canopy/forest; (10) architectural setting; (11) water views and sound; and (12) indoor nature.

Of the human responses to these environments there were 44 mentions of the various psychological, physical, emotional and mental categories across the SLRs analysed, and these are correlated against the particular biophilic element which has been shown to have a connected positive effect. Given the space available in this article, it is not possible to comment on every point in the matrix. However, some highlights are worth mentioning:

- From the point of view of the biophilic elements, connection to nature is the most used term, followed closely by biophilic features. Other terms are sparsely used, although natural light, control of lighting, views of nature/virtual elements, natural materials (especially timber/wood) and indoor environmental quality (IEQ) are also used in a few reviews.
- In terms of 'human improvement' when associated with a connection to nature, the most mentioned impacts are on academic performance and affect. In this category, we also see numbers of mentions of: flourishing, joy, happiness and pleasure; health and wellness; mental health and fatigue; restoration and relaxation; social interaction, stress reduction and subjective well-being.
- Highlights in the generic biophilic features impact categories include an impact on academic performance; creativity, curiosity, innovation and inspiration; flourishing, joy, happiness and pleasure; productivity(student); and self-esteem, regulation and confidence.
- It is also worth noting that academic performance is mentioned multiple times in 10 of the 12 biophilic element categories.

Table 3. Matrix of Findings.

	Biophilic Elements Referred to in the SLRs											
Human Improvement	**Connection to Nature**	**Biophilic Features**	**Natural Light and Control**	**Views of Nature & Virtual**	**Natural Materials Esp Timber**	**Indoor Environment Quality**	**Campus Green Space**	**Green Adjacent to Campus**	**Increased Tree Canopy/Forest**	**Architectural Setting**	**Water Views & Sound**	**Indoor Nature**
Academic performance	5	4	3	3		3	1	5	1			1
Affect (positive)	3		1							2		
Alertness			1									
Anxiety	2	1			1							
Attentiveness	3	2		1	1							
Behaviour, anger	5	1										
Blood pressure, heart rate, sweat		2			1							
Cognitive & intellectual	7	2	1			1			1			
Cognitive speed		1	1			1						
Cognitive play	1											
Competence	1											
Coordination	1											
Concentration	2	1	1									
Creativity, curiosity, innovation & inspiration	2	6										
Depression	2	1										
Doctor reduced diagnoses	4	1										
Energy levels	1											
Emotional mood & development	6	3			1							
Stimulation & excitement	1	1										
Focus/alertness	1											

Table 3. *Cont.*

	Biophilic Elements Referred to in the SLRs											
Human Improvement	**Connection to Nature**	**Biophilic Features**	**Natural Light and Control**	**Views of Nature & Virtual**	**Natural Materials Esp Timber**	**Indoor Environment Quality**	**Campus Green Space**	**Green Adjacent to Campus**	**Increased Tree Canopy/Forest**	**Architectural Setting**	**Water Views & Sound**	**Indoor Nature**
Flourishing, joy, happiness and pleasure	3	4	1	1		1				1		1
Health & wellness	3	2	2	1		1	2					
Hyperactivity reduction /ADHD	2	1										
Imagination	1											
Impulse control		1										
Independent thought	1											
Life satisfaction	1	1										
Memory, retention	1	2			1		1					
Mental health, fatigue	7	2										
Mindfulness & spiritual wellbeing	2											
Moral development	1											
Motivation	1	1			1							
Movement & exploration	1	1								1		
Psychosomatic symptoms												
Productivity (student)	1	3										
PTSD		1										
Quality of life							1					
Restoration & relaxation	5	2		1	3		1			1	1	

Table 3. *Cont.*

	Biophilic Elements Referred to in the SLRs											
Human Improvement	**Connection to Nature**	**Biophilic Features**	**Natural Light and Control**	**Views of Nature & Virtual**	**Natural Materials Esp Timber**	**Indoor Environment Quality**	**Campus Green Space**	**Green Adjacent to Campus**	**Increased Tree Canopy/Forest**	**Architectural Setting**	**Water Views & Sound**	**Indoor Nature**
Self-esteem, regulation & confidence	3	4										
Social interaction	4	1										
Stress reduction	7	1								1		
Temperature campus							1					
Wellbeing (Subjective)	5		1		1		2					

The numbers of mentions in the SLRs noted above suggest a strong positive connection between various biophilic elements and resulting positive human responses. It has been suggested that some of the measures of these human responses are objective, and some are subjective. Each of the SLRs has notes on which of their identified human responses are measurable. Apropos subjective assessment and 'measurement', it is also possible to evaluate this through the concept of 'expert elicitation' using the IDEA protocol—investigate, discuss, estimate and aggregate [19]. It is clear that there is a significantly increasing amount of evidence-based peer-reviewed research that supports a strong link between many physical, psychological, spiritual and medical benefits in the workplace.

Thus, it can be said that this emerging research in school design illustrates that if schoolteachers and students are exposed to effective biophilic design and biophilic urbanism planning and design elements, they will have an enhanced sense of health and well-being, and many indicators in physical, psychological, spiritual and medical realms can be improved. Related studies discussed above regarding the openness, ceiling height, volume and curvature can also have a positive impact on health and well-being. This is completely at odds when the design of a standard classroom is considered, some 150 years on from when the concept was first developed.

The research is complex and cross-disciplinary, using mixed methods across many sectors of the built and natural environment. Furthermore the 70 or so health and wellbeing factors mentioned across the SLRs makes comparative analysis difficult. The significant amounts of relevant research—perhaps some 600 or so peer-reviewed papers being analysed in the SLRs alone—is very encouraging. This is becoming to look like sufficient quality evidence of the positive connection between nature and health and well-being in schools to be placed in front of policymakers and treasuries to provide more focussed funding to make schools biophilic models of healthier places of learning.

Such a biophilic approach would show leadership to the whole community that schools could lead the way in biophilic design for health and well-being and can demonstrate what is possible in all workplace sectors, including homes and the public realm.

6. Conclusions and Further Research Directions

If we critically scrutinise the school-oriented synthesis of systematic literature reviews analysed in this manuscript, the individual papers referenced and cited within each SLR review analysis need to be summarised and assessed for their methodological thoroughness and validity. This would mean that the total of 600 or so articles referred to within the systematic reviews discussed above would need summarising and ranking for methodological validity. Ulrich had a team of eight people who contributed to his biophilic healthcare planning and design project.

Such an approach may be the next step in the process of developing a robust case for increasing the biophilic nature of school design to enhance health and well-being. Meanwhile, this critical synthesis and analysis of evidence-based systematic reviews considered in this paper can be seen as an interim step in seeking scholarly and educational sector support for such an approach.

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