

## Article

# Biophilic Design and Children's Well-Being in Kindergartens in Henan, China: A PLS-SEM Study

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**Abstract:** Urbanisation and reduced natural spaces pose increasing challenges to children's holistic development in early learning environments. This study investigates how four biophilic design elements—water, plants, animals, and ecosystems—affect the physical, mental, and social well-being of kindergarten children in Henan Province, China. A quantitative questionnaire survey was conducted with children, parents, and teachers from four selected kindergartens. The questionnaire consisted of three parts: demographic information, preferences toward biophilic design elements, and perceived impacts of these elements on children's development. Considering young children's limited ability to self-report psychological and emotional states, children's preferences were statistically compared to those of parents and teachers using IBM SPSS Statistics Version 26. Results showed no significant differences; thus, data from parents and teachers were retained for further analysis. Subsequently, Partial Least Squares Structural Equation Modelling (PLS-SEM) was applied to explore relationships between biophilic elements and children's developmental outcomes. Results indicated that water and animal elements were associated with higher levels of physical activity and psychological resilience, plants were linked to greater social adaptability, and ecosystem landscapes were related to overall indicators of child development. Because the dataset is geographically limited, these quantitative results should be interpreted as exploratory evidence. Importantly, these interventions can be feasibly incorporated into existing facilities, offering practical avenues for swift implementation. To better facilitate such practical implementation, this study synthesises key findings into a comprehensive framework, explicitly outlining how these biophilic elements can be prioritised and effectively integrated into kindergarten designs. Future research is recommended to examine long-term effects and cultural adaptability.

**Keywords:** biophilic design; health and well-being; kindergarten; feasibility; PLS-SEM



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## 1. Introduction

Rapid urbanisation and economic development have led to the loss of natural spaces and increased air pollution, significantly impacting children's health [1–4]. These environmental changes restrict children's access to nature, contributing to respiratory ailments, psychological

stress, and cognitive developmental impairments [5,6]. Additionally, reduced outdoor activities limit physical exercise, further affecting children's physical and mental health [7,8].

To address these challenges, this study investigates how biophilic design—integrating four key natural elements (water, plants, animals, and ecosystems)—can foster children's physical, mental, and social health in Chinese kindergartens [9,10]. The originality of this research lies in its focus on real-world kindergarten settings within a rapidly urbanising region of China, offering novel insights into culturally specific implementations of biophilic design (BD) [11,12]. Unlike previous studies that primarily concentrate on Western contexts or single design elements, this research provides a comprehensive framework that merges established BD patterns (Browning's 14 Patterns) and attributes (Kellert's 24 Attributes) [9,12,13]. A robust statistical analysis technique, Partial Least Squares Structural Equation Modelling (PLS-SEM), was employed to evaluate the relationships between each biophilic element and multiple dimensions of child development. This methodological choice addresses current gaps in measuring, analysing, and comparing the impacts of biophilic interventions on children. The sections below first introduce the theoretical underpinnings and scope of this work, then details the methodology, and finally assesses the accuracy of the PLS-SEM model by applying rigorous reliability and validity checks [14].

### 1.1. Optimising Biophilic Elements in Kindergarten Design

BD has emerged as a prominent strategy for improving human health and well-being, particularly in educational settings where its impact on children's development is significant [15–17]. Traditional school architecture is being supplanted by student-centric designs that prioritise interactions with nature to support children's holistic growth [18–20].

Since 2001, BD has expanded to incorporate diverse facets of human interaction with natural elements in architectural contexts [21]. Heerwagen and Hase [22] first classified biophilic architecture based on natural qualities such as visual aesthetics, water, and biodiversity. Kellert, et al. [23], in their seminal work, *Biophilic Design: The Theory, Science, and Practice of Bringing Buildings to Life*, outlined two dimensions, six elements, and 72 attributes of BD. Terapin Bright Green refined Cramer and Browning [24] three biophilic architecture categories into 14 design patterns [25], while Kellert and Calabrese [26] refined these into a 24-attribute framework covering direct and indirect nature interactions alongside spatial experiences.

Browning and Ryan [27] added further depth, dividing responses to nature into three categories: “nature in the space”, “nature analogies”, and “natural analogies in space”. Despite variations in classification, these frameworks converge on a shared goal: enhancing environmental quality, human health, and productivity through BD [28,29].

Applying BD to kindergartens presents unique challenges, largely stemming from the specialized conditions of early childhood settings—for instance, ensuring child-friendly safety standards and designing age-appropriate features. Moreover, any framework must provide meaningful nature interactions that foster health and well-being. Effective implementation necessitates adherence to core principles such as sustained engagement with nature, human adaptations to nature, and emotional connections to specific environments [26,27].

Empirical evidence underscores the importance of direct visual engagement with nature for children's cognitive and emotional development. Benfield, et al. [30] and Wijesooriya and Brambilla [31] found that exposure to natural landscapes enhances cognitive performance and well-being compared to artificial environments. The activation of the visual cortex enhances pleasure receptors, sustains interest, and accelerates stress recovery. Authentic natural views, as opposed to high-quality simulations, have been shown to increase recovery rates by 1.6 times, underscoring the critical importance of genuine natural experiences [32]. Moreover, children demonstrate a sustained interest in natural settings even with repeated exposure, indicating their enduring engagement with such

environments [33]. This prolonged interaction is particularly valuable for kindergarteners, as it facilitates the visual expression of emotions and feelings [34–36].

This study addresses two main issues. First, it highlights the need for optimal BD elements in kindergartens to promote children’s health and well-being. While BD in educational settings offers significant health benefits, the application of such design concepts in kindergartens remains understudied. This research focuses on optimising biophilic elements in both indoor and outdoor kindergarten environments to enhance children’s health and development. Second, the study develops a structural equation model to evaluate the impact of biophilic elements on child development through path analyses. These analyses utilise advanced statistical techniques, such as PLS-SEM, to quantify and assess the effects of biophilic features on children’s well-being in real-world educational contexts.

Building on the aforementioned discussion, the authors combined Browning’s 14 patterns [25] with Kellert’s 24 attributes [27]. These two frameworks intersect to focus on direct natural experiences, including water, plants, animals, landscapes, and ecosystems, as illustrated in Table 1. The authors then qualitatively examined these four factors to explore kindergarten architectural BD patterns. Water, plants, animals, natural landscapes, and ecosystems were treated as variables in the quantitative biophilic model (see Table 2), revealing their practical applications and implementation strategies in both indoor and outdoor kindergarten environments (see Supplementary Materials 1 for more details).

**Table 1.** Overlapping elements between the two BD frameworks.

| Browning’s 14 Patterns                      |                                                                   | Kellert’s 24 Attributes             |
|---------------------------------------------|-------------------------------------------------------------------|-------------------------------------|
| Example of Visual Connection with Nature    |                                                                   | Direct Experience of Nature         |
| Naturally Occurring                         | Simulated or Constructed                                          |                                     |
| • Natural flow of a body of water           | • Mechanical flow of a body of water                              | • Water                             |
| • Vegetation, including food-bearing plants | • Green wall                                                      | • Plants                            |
| • Animals, insects                          | • Koi pond, aquarium                                              | • Animals                           |
| • Terrain, soil, earth                      | • Highly designed landscapes<br>• Artwork depicting nature scenes | • Natural landscapes and ecosystems |
| • Fossils                                   | • Video depicting nature scenes                                   | • Light                             |
|                                             |                                                                   | • Air                               |
|                                             |                                                                   | • Weather                           |
|                                             |                                                                   | • Fire                              |

Both Browning’s 14 Patterns [25] and Kellert’s 24 Attributes [26] underscore direct and indirect nature connections but differ in scope: Browning emphasises architectural applicability, while Kellert offers a granular taxonomy of human/nature interactions. Examining their overlap and divergence (Table 1) yields a holistic approach for kindergartens, where children’s developmental needs demand multisensory engagements and structured attributes. Although additional features may also be considered under the umbrella of biophilic design, a systematic review [37] identified water, plants, animals, and ecosystems as the most impactful direct-experience elements for early childhood, particularly in Chinese kindergarten contexts where cultural norms and resource availability make these interventions both feasible and relevant. Water fosters playful engagement, plants enhance air quality and sensory experiences, animals (small, harmless) encourage empathy, and ecosystems integrate natural elements for holistic exploration. These four elements have

been carefully discussed for their suitability in China-based kindergarten settings, aligning with the main purpose of this study while still allowing other researchers to expand, adapt, or refine these elements in future investigations.

Emerging evidence further indicates that children benefit not only from direct nature contact but also from the visual complexity inherent in many natural forms. Mid-range fractal patterns, mirror symmetry, and rich colour contrasts—features ubiquitous in streams, leaf venation, and animal pelage—have been linked to reduced physiological stress [38] and enhanced visuospatial working memory [39]. In learning settings, classrooms that embed self-similar or symmetrical motifs correlate with greater on-task behaviour and persistence [40]. Recognising that the four focal elements in this study (water, plants, animals, ecosystems) naturally contain fractal-like or symmetrical structures strengthens the theoretical bridge between biophilic design and both emotional restoration and cognitive stimulation. Although the present work does not quantify fractal geometry per se, integrating this visual-complexity perspective enriches the explanatory scope of the model and offers a testable avenue for future research.

**Table 2.** Implementation of BD elements in kindergartens.

| Elements                              | Variables                                                                                     |
|---------------------------------------|-----------------------------------------------------------------------------------------------|
| Water                                 | A. Classroom aquarium                                                                         |
|                                       | B. Three-dimensional miniature fountain                                                       |
|                                       | C. Outdoor ground-level fountain installation                                                 |
|                                       | D. Water puddle (for play)                                                                    |
| Plants                                | A. Installing flower pots in the classroom                                                    |
|                                       | B. Installing a green wall (bio wall) in the classroom                                        |
|                                       | C. Setting up biodiversity landscapes around the campus                                       |
|                                       | D. Having a view of plant landscapes from windows                                             |
|                                       | E. Incorporating greenery in platforms or aerial balconies within the teaching building       |
|                                       | F. Integrating outdoor greenery with the semi-enclosed corridors of the school                |
|                                       | G. Installing real plant specimens in the classroom                                           |
|                                       | H. Greening the kindergarten roof                                                             |
| Animals                               | A. Real non-threatening animals                                                               |
|                                       | B. Animal specimens                                                                           |
|                                       | C. Setting up feeding and breeding spaces in kindergartens                                    |
|                                       | D. Decorating classrooms with shells, beehives, and synthetic animal fur                      |
| Natural Landscapes<br>&<br>Ecosystems | A. Spaces for planting different plants or crops                                              |
|                                       | B. Placing obstacles, such as rocks, along paths frequently used by children                  |
|                                       | C. Maximising the quantity of soil, rocks, water bodies, and plants within constrained spaces |
|                                       | D. Integrating authentic natural elements into children's indoor and outdoor activity areas   |

### 1.2. Assessment of Children's Health and Well-Being

Research indicates that BD significantly contributes to children's physical, cognitive, social, and emotional development. Building Jean Piaget's recognition of children's unique developmental characteristics, subsequent studies have explored the complex influences shaping child health and growth. These studies highlight the impact of physical and environmental factors on physiological health, cognitive development, emotional regulation, social adaption, and moral well-being [41–45].

Evidence underscores that direct visual engagement with nature, integral to BD frameworks, improves children's physical, psychological, social, and moral health [31,46–50]. Complementary research at the intersection of neuroscience, human health, and architectural design further reveals strong correlations between exposure to nature and improved cognitive functions, attention restoration, and mental engagement [33,51–55].

This section summarises research demonstrating that natural elements within kindergarten environments promote physical and mental health, social skills, and moral development. These findings provide a robust foundation for fostering healthy growth in early childhood education settings. Table 3 (see Supplementary Materials 2 for more details), presented in the subsequent analysis, outlines these relationships and highlights the positive impacts of BD on children’s well-being. Further details regarding Tables 1–3 are discussed in Huizi, et al. [37].

**Table 3.** Health benefits of BD in various domains.

| Domain                             | Findings/Variables                                                                                                       |
|------------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| Physical Health                    | 1. Plants regulate and purify indoor air quality, enhancing children’s comfort.                                          |
|                                    | 2. Improve allergies and immunity.                                                                                       |
|                                    | 3. Promote physical activity and reduce sedentary behaviour.                                                             |
|                                    | 4. Reduce obesity.                                                                                                       |
|                                    | 5. Green facilities encourage children to participate in climbing and jumping activities.                                |
|                                    | 6. Biodiverse spaces captivate children’s interest, encouraging participation and increasing the frequency of activities |
| Mental Health                      | 1. Enhance imagination.                                                                                                  |
|                                    | 2. Boost creativity.                                                                                                     |
|                                    | 3. Improve cognitive abilities.                                                                                          |
|                                    | 4. Increase attention span.                                                                                              |
|                                    | 5. Enhance resilience.                                                                                                   |
|                                    | 6. Improve emotional regulation.                                                                                         |
|                                    | 7. Promote a state of relaxation.                                                                                        |
| Social Adaptation and Moral Health | 1. Enhance social skills.                                                                                                |
|                                    | 2. Increase adaptability.                                                                                                |
|                                    | 3. Improve exploratory abilities.                                                                                        |
|                                    | 4. Enhance cooperation.                                                                                                  |
|                                    | 5. Foster independence.                                                                                                  |
|                                    | 6. Reduce excessive daydreaming.                                                                                         |

## 2. Research Methodology

The primary data analysis technique for this study is Partial Least Squares Structural Equation Modelling (PLS-SEM), chosen over covariance-based SEM (CB-SEM) due to its effectiveness in exploratory research involving smaller samples, complex path models, and non-normal data [14]. Unlike theory-driven CB-SEM, which assumes larger samples and strict distribution requirements, PLS-SEM maximises explained variance among latent constructs and tolerates imperfect model specifications—key advantages when examining how multiple biophilic design elements (water, plants, animals, ecosystems) influence children’s physical, mental, and social development. The following subsections detail the key model parameters, data collection procedures, sample size calculations, and methods used to evaluate model accuracy [56,57].

### 2.1. Model Parameters and Accuracy Assessment

To explore the influence of BD elements on children’s health and well-being, this study adopts a model derived from the literature review presented in Huizi, et al. [37]. Four exogenous variables (water, plants, animals, and ecosystem landscapes) and three endogenous variables (physical health, mental health, and social awareness) comprise seven constructs, each measured via multiple indicators (Supplementary Materials 3).

Internal consistency reliability was evaluated through Composite Reliability (CR) and Cronbach’s Alpha, while convergent validity was examined using factor loadings and Average Variance Extracted (AVE). Discriminant validity was checked via the Fornell–

Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio. Predictive accuracy was assessed by applying  $Q^2$ predict and comparing root mean square error (RMSE) values between PLS-SEM and linear modelling. Variance Inflation Factor (VIF) values were used to confirm that no major multicollinearity issues were present.

Figure 1 illustrates the conceptual framework. Arrows from the four exogenous constructs (water, plants, animals, and ecosystems) to the three endogenous constructs (physical health, mental health, and social adaptation) indicate hypothesised direct effects based on this framework, the following hypotheses are proposed:

**H1.** *Water elements in kindergartens positively influence children’s physical health, mental well-being, and social adaptability.*

**H2.** *Plant elements in kindergartens positively influence children’s physical health, mental well-being, and social adaptability.*

**H3.** *Animal elements in kindergartens positively influence children’s physical health, mental well-being, and social adaptability.*

**H4.** *Ecosystem elements in kindergartens positively influence children’s physical health, mental well-being, and social adaptability.*

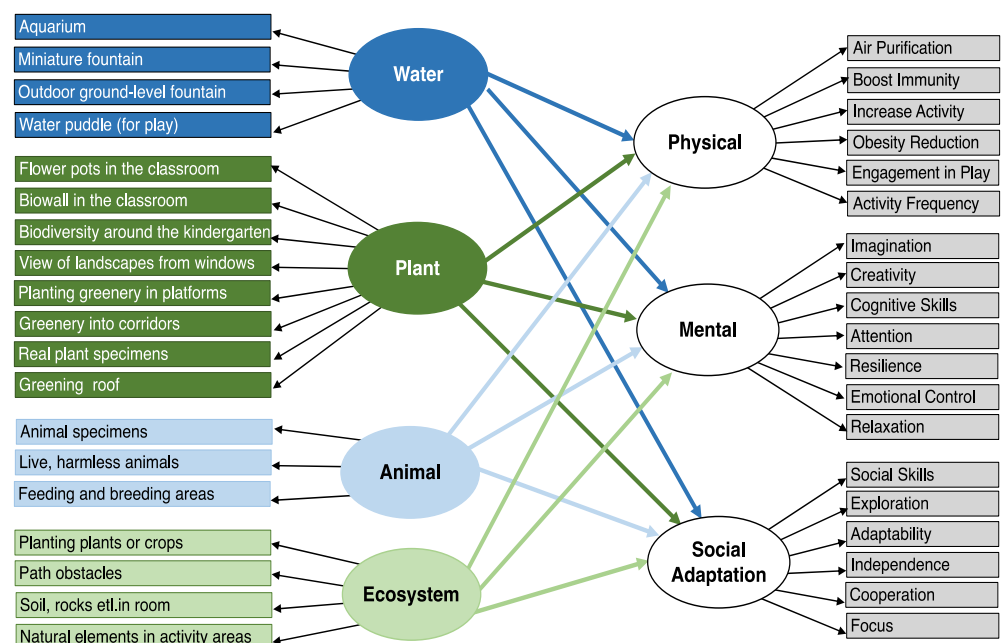


**Figure 1.** Conceptual framework.

## 2.2. Target Respondents and Sample Size

The study was conducted in four kindergartens in Henan, Central China, selected for their emphasis on children’s health and well-being through the application BD principles in both indoor and outdoor environments.

This quantitative research involved children, parents, and teachers from the selected institutions. Ethical approval was obtained from the Universiti Malaya Ethics Committee (UM.TNC2/UMREC\_2858). Prior to data collection, parents were provided with an informed consent form (Supplementary Materials 9) detailing the study’s objectives, procedures, confidentiality measures, and their rights to withdraw at any stage. Parents signed these consent forms on behalf of their children, adhering to ethical guidelines outlined by

the Ethics Committee. Parents and teachers separately signed their own informed consent forms, emphasizing their voluntary participation and full awareness of the research process.

To analyse the data, Partial Least Squares Structural Equation Modelling (PLS-SEM), a robust multivariate analysis tool [58,59], was employed, following SPSS version 26. PLS-SEM sample size estimation follows several guidelines, including the “rule of ten”, which states that the sample size should be at least ten times the number of indicators used to measure constructs [60]. The initial sample size was set at 70, based on 7 research constructs. However, Kock [61] and Kock and Hadaya [62] argue that the rule of ten may underestimate the necessary sample size. Therefore, this study employed the sample size determination approach suggested by Cochran [63] for categorical data, appropriate for survey research involving proportions. The calculation was based on a confidence level of 95%, corresponding to a Z-score of 1.96 and a margin of error of 5% (0.05), indicating the acceptable range of error in the results. A population proportion ( $p$ ) of 0.5 was used, representing the most conservative estimate for maximum variability.

Given that the average number of children enrolled in kindergartens in Henan Province over the past decade has been approximately 3.95 million [64], the formula for large populations was applied:

$$n = \frac{Z^2 \times p \times (1 - p)}{E^2}$$

where

$n$  is the required sample size;

$Z$  is the Z-score corresponding to the desired confidence level (1.96 for 95%);

$p$  is the population proportion (assumed to be 0.5 for maximum variability);

$E$  is the margin of error (0.05 in our study).

Substituting the given values:

$$n = \frac{(1.96)^2 \times 0.5 \times (1 - 0.5)}{(0.05)^2} = \frac{3.8416^2 \times 0.25}{0.0025} = \frac{0.9604}{0.0025} = 384.16$$

Therefore, the estimated sample size required for the children’s group is approximately 385 respondents to meet the targeted confidence level and margin of error.

For the parents and teachers group, since each child typically has at least one parent involved in their education and interacts with teachers, the combined population of parents and teachers associated with kindergarten children is also extremely large. Given this effectively infinite population size [65], and considering that parents and teachers are being treated as one group for this study, the same sample size calculation applies:

$$n = \frac{Z^2 \times p \times (1 - p)}{E^2} = 384.16$$

Thus, the estimated sample size required for the parents and teachers group is also approximately 385 respondents.

In summary, to achieve the desired confidence level and margin of error, the study aimed to collect data from approximately 385 children and a combined total of 385 parents and teachers. Although the sample sizes are the same for both groups, this is appropriate because both groups have large population sizes, and the calculations are based on the same statistical parameters. Calculating the sample sizes for each group based on their large populations ensures that the findings are statistically valid and representative.

During participant recruitment, researchers conducted a screening process (see Figure 2 for the screening diagram). Ultimately, in collaboration with four local kindergartens that had already incorporated or planned to incorporate nature-based features, administrative approval was secured to conduct on-site surveys. Parents and teachers were informed of

the study's objectives through official kindergarten communication channels (e.g., WeChat groups and parent/teacher meetings). Children's participation was facilitated only after parental consent forms were signed (see Supplementary Materials 9 for the consent form template). Figure 3 presents the external layout of the four kindergartens.



**Figure 2.** Screening process flowchart.



**Figure 3.** Exterior views of the four kindergartens involved in the study: (A) Great Man Kindergarten; (B) One Infinity Academy Kindergarten; (C) Haiwen Kindergarten; (D) Muzi International Kindergarten.

### 2.3. Data Collection Instrument

The indicators used in the survey were identified through a comprehensive literature review (see Supplementary Materials 3). The questionnaires for both groups began with demographic questions. Children were asked a single, simple question regarding age, whereas the parent and teacher questionnaire included queries about gender, education level, and the amount of weekly time spent with children. Responses from parents who spent fewer than two days a week with their children were excluded to ensure that the data reflected meaningful involvement in their children's lives.

The second section of the questionnaire focused on BD preferences, presented through a 5-point Likert scale (strongly agree = 1 to strongly disagree = 5). This scale was adapted to address different comprehension levels. Parents received text-based questions, while children aged 4–6 completed a pictorial version designed to minimise reliance on text [66]. Each question included emojis corresponding to Likert-scale options, enabling children to indicate preferences in an intuitive, visual manner [67]. Previous research has demonstrated that children in the 4–6 age range can validly respond to such simplified pictorial scales, provided that adult guidance is neutral and items are kept succinct and visually engaging [68]. This approach reduces cognitive load, limits reading demands, and helps young respondents focus on the intended question without extensive text.

The third section was exclusive to Group 2 (parents and teachers) and included items examining children's health and well-being with a 5-point Likert scale (very significant = 1 to not significant = 5). These items incorporated more advanced psychological terms and were not presented to children, given the complexity of concepts involved. In this study, "health" was operationalised through behavioural proxies (e.g., reported frequency of physical activity) and adult perceptions of psychological comfort; no physiological or clinical measures were taken. Collecting feedback from parents and teachers therefore provided a broader understanding of how biophilic environments might influence children's well-being within everyday educational contexts.

A pilot survey was conducted prior to the main study, involving 77 parents and teachers for the purpose of verifying the validity and practicality of the responses [69]. The reliability of key indicators was tested through PLS-SEM analysis in this pilot phase. Based on the results, two indicators—"social 6" and "animal 4"—were removed (Supplementary Materials 4 provides further details). This pilot stage also served to confirm that the simplified pictorial questionnaire design for children was feasible and that the items were appropriate for their cognitive level.

In the main survey, after data collection, SPSS version 26 was used to identify any significant differences in preferences between children and their parents or teachers, as captured in Part Two of the questionnaires. Where no statistically significant differences emerged, Partial Least Squares Structural Equation Modelling was applied to analyse Parts Two and Three of the parents' questionnaire. This multi-stage process was intended to ensure coherence between the children's and adults' responses and to enable a reliable investigation of the relationships between the variables of interest.

#### *2.4. Biophilic Elements Assessment*

In PLS-SEM, Importance–Performance Map Analysis (IPMA) evaluates both the importance and performance of biophilic components within the model. IPMA examines the path coefficients of the constructs and the corresponding performance scores. It shows how independent variables impact the dependent variables and rescales performance scores to standardised values (0 to 100%) for easier comparison [14]. This analysis helps identify variables that have high importance but low performance, revealing areas where interventions could improve outcomes. In the context of educational settings, IPMA is particularly valuable, as it provides insights into which aspects of kindergarten biophilic designs are most influential but may not be performing optimally. This information can guide targeted interventions to optimise children's health and well-being.

#### *2.5. Data Analysis*

The analysis was conducted in three stages. First, invalid children's questionnaires with scribbles, uniform responses, or incomplete submissions were discarded; out of 391 collected questionnaires from children, 386 were considered valid and retained for analysis. Likewise, parent and teacher questionnaires from those who spent less than two days a week with their children or had identical responses were removed; of the 435 collected questionnaires from parents and teachers, 388 were included in the final analysis. Next, IBM SPSS Statistics 26 was used to test normality and determine the most suitable comparison analysis methods for children's and parents'/teachers' surveys. SmartPLS was then utilised to identify the key health and well-being factors for children. PLS-SEM, a variance-based structural equation modelling data analysis tool [70], was employed for this study. It comprises two models: the measurement model (outer model) and the structural model (inner model) (Figure 4). PLS-SEM was ultimately selected for its strong predictive orientation and suitability for exploratory studies [14,59,71]. It

effectively addresses the study's aims by accommodating the non-normal data distribution (Kolmogorov–Smirnov, Shapiro–Wilk tests; see Supplementary Materials 5) and allowing simultaneous examination of multiple constructs. In contrast, CB-SEM typically requires larger samples and stricter assumptions, posing difficulties for an emerging framework such as the one developed here. Overall, PLS-SEM's strengths in handling complex relationships, smaller samples, and non-normal data justified its use as the primary analytical tool.

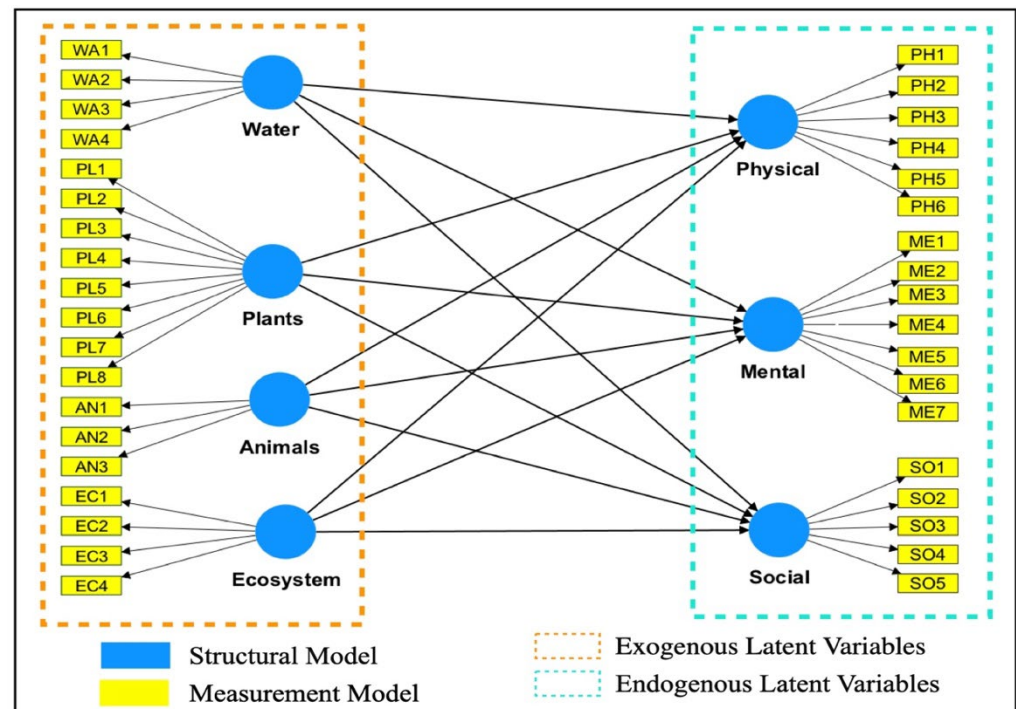


**Figure 4.** The final PLS-SEM model illustrates the impact of biophilic elements in kindergartens on children's health and well-being.

This study utilised two reflective measurement models for all latent constructs, as indicated by the single-headed arrows pointing from the indicators to the constructs. A consistent PLS-SEM algorithm along with bootstrapping was applied [72].

### 3. Results

#### 3.1. Data Normality and Comparative Analysis

Normality was assessed using Kolmogorov–Smirnov (0.066–0.092 for parents and teachers; 0.078–0.097 for children) and Shapiro–Wilk tests (all  $> 0.973$ ), indicating non-normal distributions (Supplementary Materials 5). Given these findings, non-parametric or robust statistical methods, such as Partial Least Squares Structural Equation Modelling (PLS-SEM), were deemed appropriate, as they do not assume data normality.

To address potential response bias and ensure a robust comparative analysis, the Mann–Whitney U test was applied to compare responses from Group 1 (children) with those from Group 2 (parents and teachers). This test specifically evaluated group perceptions regarding the BD components of water, plants, animals, and ecosystems within kindergarten environments. Results demonstrated no statistically significant differences across these elements ( $p > 0.05$ , Table 4), indicating a general consensus among children, parents, and teachers on the significance of biophilic elements. Nonetheless, it is important to acknowledge the possibility of social desirability bias or potential adult over- or underestimation of children's preferences. Given the inherent limitations of children's self-reported responses regarding complex constructs, PLS-SEM was selected to analyse data exclusively

from parents and teachers. This approach provides more reliable insights and mitigates the potential biases inherent in children’s subjective assessments.

**Table 4.** Mann–Whitney U test results for biophilic elements in kindergartens.

|                        | Water      | Plant      | Animals    | Ecosystem  |
|------------------------|------------|------------|------------|------------|
| Mann–Whitney U         | 62,667.500 | 61,771.000 | 61,838.000 | 61,515.000 |
| Z                      | −0.163     | −0.491     | −0.468     | −0.586     |
| Asymp. Sig. (2-tailed) | 0.871      | 0.624      | 0.640      | 0.558      |

### 3.2. Assessment of Hypothesised Path Relationships

The evaluation of measurement models was the first step in PLS-SEM analysis [73]. Following guidelines provided by Hair Jr, et al. [59], three key aspects were assessed: internal consistency reliability, convergent validity, and discriminant validity. These components ensured the integrity and efficacy of the reflective measurement model used in this study.

First, composite reliability scores, ranging from 0 to 1, were used to evaluate internal consistency. Higher values indicated stronger reliability. For exploratory research, a threshold of 0.70 was deemed acceptable [72]. All constructs in this study exceeded this threshold, confirming the reliability of the instruments used (Supplementary Materials 6).

Secondly, convergent validity was assessed using two key indicators: outer loadings and Average Variance Extracted (AVE). Outer loadings needed to meet a minimum threshold of 0.70 and be statistically significant ( $p < 0.05$ ). Similarly, AVE values were required to be at least 0.50 [59,72]. All constructs in this study achieved AVE values above 0.50, and outer loadings exceeded the recommended threshold, with  $p$ -values below 0.05 (Supplementary Materials 6).

Finally, discriminant validity measures the uniqueness of a construct within the model [59,74]. Three tests were applied: indicator cross-loadings, the Fornell–Larcker criterion, and the Heterotrait–Monotrait (HTMT) ratio [72]. All indicators demonstrated higher loadings on their respective constructs compared to others in the cross-loading matrix. The square roots of AVE values exceeded inter-construct correlations, confirming construct distinctiveness. HTMT values were below the threshold of 0.85, indicating no significant overlap among constructs. These comprehensive tests demonstrated that all constructs were sufficiently distinct (Supplementary Materials 7).

The robust evaluation of measurement models validated the reliability and precision of the study’s instruments. Each tool effectively measured its intended construct, captured variability accurately, and maintained clear distinctions among constructs. This thorough validation process ensured that the findings were credible and well supported.

### 3.3. Evaluation of Structural Model

The structural model was evaluated using PLS-SEM to determine its efficacy, following the guidelines of Fornell and Larcker [73]. The evaluation encompassed key metrics, including collinearity, path coefficients,  $R^2$ ,  $f^2$ ,  $Q^2$ , and model fit, as outlined by Chua [72]. These metrics collectively confirmed the model’s theoretical relevance and robustness. Collinearity was examined using the Variance Inflation Factor (VIF) to assess the independence of predictors. The observed VIF values, which were significantly below 5, ensured the model’s clarity and dependability by demonstrating predictor independence and distinct contributions (see Supplementary Materials 8).

#### 3.3.1. Impact and Predictive Accuracy of BD on Children’s Health and Well-Being

The PLS-SEM structural model was employed to investigate the impact of BD features (water, animals, plants, and ecosystems) on children’s mental, physical, and social health in kindergarten environments.

Figure 5 highlights the strength and significance of relationships between variables using path coefficients. All path coefficients were statistically significant, confirming the proposed relationships and supporting the study's hypotheses. T-values exceeded the threshold of 1.96 for a 95% confidence interval, and  $p$ -values were reported as 0.00, substantiating the validity of these findings [72]. In hypothesis testing, the t-statistic determines whether a hypothesis is accepted or rejected. Since the absolute t-statistic for all paths exceeded 1.96, hypotheses H1, H2, H3, and H4 were accepted, with no evidence warranting their rejection.

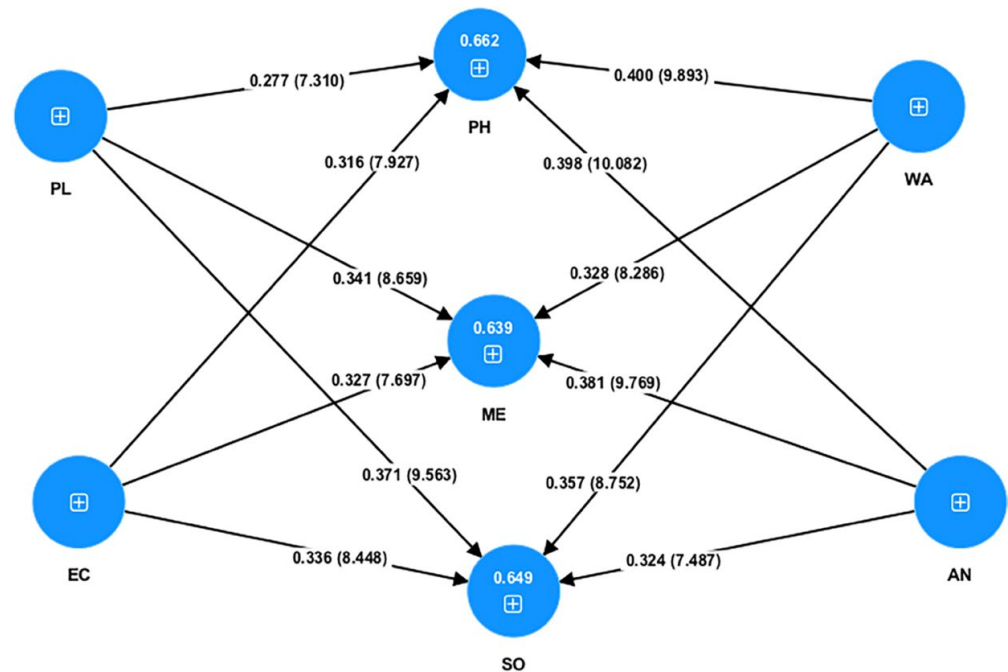


**Figure 5.** Structural equation model showing standardised path coefficients and t-statistic.

The coefficient of determination ( $R^2$ ) was used to evaluate how well the model accounted for variations in the dependent variables. An  $R^2$  value approaching 1 suggests that the model explains a significant proportion of the observed variance [75]. In this study,  $R^2$  values were close to 0.67 (Figure 5), indicating that the model effectively accounted for most of the variations in the dependent variables.

Effect size ( $f^2$ ) measures the influence of independent variables on dependent variables. According to Cohen [76],  $f^2$  values of 0.02 to 0.15 indicate small effects, values from 0.15 to 0.35 represent medium effects, and values exceeding 0.35 suggest large effects. As shown in Table 5, water demonstrated a significant impact on physical and social outcomes, animals had a notable effect on mental and physical outcomes, and plants strongly influenced social outcomes.

**Table 5.** Effect sizes of predictors on children's health and well-being outcomes.

| Predictor | Dependent Variable | Effect Size ( $f^2$ ) | Effect Category |
|-----------|--------------------|-----------------------|-----------------|
| Animals   | Mental             | 0.385                 | Large           |
| Animals   | Physical           | 0.449                 | Large           |
| Animals   | Social             | 0.287                 | Medium          |
| Ecosystem | Mental             | 0.278                 | Medium          |
| Ecosystem | Physical           | 0.278                 | Medium          |
| Ecosystem | Social             | 0.303                 | Medium          |
| Plants    | Mental             | 0.311                 | Medium          |

**Table 5.** *Cont.*

| Predictor | Dependent Variable | Effect Size ( $f^2$ ) | Effect Category |
|-----------|--------------------|-----------------------|-----------------|
| Plants    | Physical           | 0.219                 | Medium          |
| Plants    | Social             | 0.379                 | Large           |
| Water     | Mental             | 0.288                 | Medium          |
| Water     | Physical           | 0.458                 | Large           |
| Water     | Social             | 0.351                 | Large           |

The model's predictive relevance ( $Q^2$ ) and root mean square error (RMSE), as presented in Table 6, confirm its strong explanatory and predictive capabilities.  $Q^2$  values exceeding 0.5 for the mental, social, and physical domains reflect substantial explanatory power [77]. Additionally, PLS-SEM demonstrated superior predictive performance compared to linear modelling, evidenced by its lower RMSE values [72].

**Table 6.** Comparison of predictive accuracy between PLS-SEM and linear modelling across mental, physical, and social adaptation constructs.

| $Q^2$ Predict     |       | PLS-SEM_RMSE | LM_RMSE |
|-------------------|-------|--------------|---------|
| Mental            | 0.534 | ME1          | 0.932   |
|                   |       | ME2          | 0.834   |
|                   |       | ME3          | 0.86    |
|                   |       | ME4          | 0.81    |
|                   |       | ME5          | 0.791   |
|                   |       | ME6          | 0.791   |
|                   |       | ME7          | 0.816   |
| Physical          | 0.553 | PH1          | 0.976   |
|                   |       | PH2          | 0.844   |
|                   |       | PH3          | 0.831   |
|                   |       | PH4          | 0.771   |
|                   |       | PH5          | 0.817   |
|                   |       | PH6          | 0.824   |
| Social Adaptation | 0.534 | SO1          | 0.943   |
|                   |       | SO2          | 0.786   |
|                   |       | SO3          | 0.806   |
|                   |       | SO4          | 0.821   |
|                   |       | SO5          | 0.79    |

### 3.3.2. Fitting the Model to Real-World Data

The Standardised Root Mean Square Residual (SRMR) and Normed Fit Index (NFI) were used to evaluate the model's fit with the observed data (Table 7). SRMR values below 0.08 and NFI values above 0.90 indicated an excellent fit [72], confirming that the model closely aligned with real-world observations. These results validate the model's robustness and practical applicability.

**Table 7.** Fit indices for saturated and estimated models in PLS-SEM.

|       | Saturated Model | Estimated Model |
|-------|-----------------|-----------------|
| SRMR  | 0.031           | 0.056           |
| d_ULS | 0.655           | 2.233           |
| d_G   | 0.429           | 0.532           |
| NFI   | 0.921           | 0.905           |

### 3.3.3. Evaluating the Impact of Elements on Child Development

IPMA was used to assess the impact of biophilic elements on children’s educational development (Table 8). Animals had the strongest impact on mental development (0.346), water on physical health (0.376), and plants on social adaptation (0.350). Ecosystems positively influenced all areas. These results underscore the value of biophilic elements in kindergarten design and provide guidance for future improvements.

**Table 8.** Assessing biophilic design for child well-being: a performance analysis.

| For Mental   |                                    |                       |           |                                      |                       |
|--------------|------------------------------------|-----------------------|-----------|--------------------------------------|-----------------------|
| Construct    | Construct Total Effects for Mental | Construct Performance | Indicator | Indicator Total Effects for Mental   | Indicator Performance |
| Animals      | 0.346                              | 43.595                | AN1       | 0.135                                | 49.185                |
|              |                                    |                       | AN2       | 0.129                                | 41.916                |
|              |                                    |                       | AN3       | 0.131                                | 40.693                |
| Ecosystems   | 0.309                              | 38.794                | EC1       | 0.099                                | 41.508                |
|              |                                    |                       | EC2       | 0.090                                | 40.761                |
|              |                                    |                       | EC3       | 0.086                                | 37.228                |
|              |                                    |                       | EC4       | 0.086                                | 35.87                 |
| Plants       | 0.325                              | 37.146                | PL1       | 0.054                                | 41.916                |
|              |                                    |                       | PL2       | 0.047                                | 39.878                |
|              |                                    |                       | PL3       | 0.055                                | 33.696                |
|              |                                    |                       | PL4       | 0.047                                | 36.141                |
|              |                                    |                       | PL5       | 0.046                                | 34.511                |
|              |                                    |                       | PL6       | 0.049                                | 35.938                |
|              |                                    |                       | PL7       | 0.051                                | 37.296                |
|              |                                    |                       | PL8       | 0.047                                | 38.383                |
| Water        | 0.311                              | 41.643                | WA1       | 0.082                                | 41.848                |
|              |                                    |                       | WA2       | 0.091                                | 39.334                |
|              |                                    |                       | WA3       | 0.085                                | 41.508                |
|              |                                    |                       | WA4       | 0.097                                | 43.886                |
| For Physical |                                    |                       |           |                                      |                       |
| Construct    | Construct Total Effects for Mental | Construct Performance | Indicator | Indicator Total Effects for Physical | Indicator Performance |
| Animals      | 0.360                              | 43.595                | AN1       | 0.141                                | 49.185                |
|              |                                    |                       | AN2       | 0.134                                | 41.916                |
|              |                                    |                       | AN3       | 0.136                                | 40.693                |
| Ecosystems   | 0.300                              | 38.794                | EC1       | 0.096                                | 41.508                |
|              |                                    |                       | EC2       | 0.087                                | 40.761                |
|              |                                    |                       | EC3       | 0.083                                | 37.228                |
|              |                                    |                       | EC4       | 0.083                                | 35.87                 |
| Plants       | 0.266                              | 37.146                | PL1       | 0.044                                | 41.916                |
|              |                                    |                       | PL2       | 0.039                                | 39.878                |
|              |                                    |                       | PL3       | 0.045                                | 33.696                |
|              |                                    |                       | PL4       | 0.038                                | 36.141                |
|              |                                    |                       | PL5       | 0.038                                | 34.511                |
|              |                                    |                       | PL6       | 0.040                                | 35.938                |
|              |                                    |                       | PL7       | 0.042                                | 37.296                |
|              |                                    |                       | PL8       | 0.038                                | 38.383                |
| Water        | 0.376                              | 41.643                | WA1       | 0.099                                | 41.848                |
|              |                                    |                       | WA2       | 0.110                                | 39.334                |
|              |                                    |                       | WA3       | 0.103                                | 41.508                |
|              |                                    |                       | WA4       | 0.118                                | 43.886                |

Table 8. *Cont.*

| Construct  | Construct Total Effects for Mental | Construct Performance | For Social |                                               |                       |
|------------|------------------------------------|-----------------------|------------|-----------------------------------------------|-----------------------|
|            |                                    |                       | Indicator  | Indicator Total Effects for Social Adaptation | Indicator Performance |
| Animals    | 0.293                              | 43.595                | AN1        | 0.115                                         | 49.185                |
|            |                                    |                       | AN2        | 0.109                                         | 41.916                |
|            |                                    |                       | AN3        | 0.111                                         | 40.693                |
| Ecosystems | 0.313                              | 38.794                | EC1        | 0.100                                         | 41.508                |
|            |                                    |                       | EC2        | 0.091                                         | 40.761                |
|            |                                    |                       | EC3        | 0.087                                         | 37.228                |
|            |                                    |                       | EC4        | 0.087                                         | 35.87                 |
| Plants     | 0.350                              | 37.146                | PL1        | 0.058                                         | 41.916                |
|            |                                    |                       | PL2        | 0.051                                         | 39.878                |
|            |                                    |                       | PL3        | 0.059                                         | 33.696                |
|            |                                    |                       | PL4        | 0.050                                         | 36.141                |
|            |                                    |                       | PL5        | 0.050                                         | 34.511                |
|            |                                    |                       | PL6        | 0.052                                         | 35.938                |
|            |                                    |                       | PL7        | 0.055                                         | 37.296                |
|            |                                    |                       | PL8        | 0.050                                         | 38.383                |
| Water      | 0.333                              | 41.643                | WA1        | 0.088                                         | 41.848                |
|            |                                    |                       | WA2        | 0.097                                         | 39.334                |
|            |                                    |                       | WA3        | 0.092                                         | 41.508                |
|            |                                    |                       | WA4        | 0.104                                         | 43.886                |

#### 4. Discussion

Survey analysis assessed the impact of BD on children’s health and well-being in four kindergartens across in Henan. This study used PLS-SEM a PLS-SEM-based analysis to develop a kindergarten biophilic assessment model based on existing BD frameworks. BD elements—water, plants, animals, and ecosystem landscapes—showed positive statistical associations with indicators of children’s health and well-being, enhancing their mental, physical, and social adaptability (significant correlation). Given the restricted sample, these statistical associations should be viewed as preliminary. (Figure 5 and Table 5 detail the results, highlighting statistically significant path coefficients and effect sizes.)

Based on the Importance–Performance Map Analysis (IPMA), the findings reveal several new insights. First, water elements (e.g., ground-level fountain, interactive water puddles) showed the strongest positive association with children’s physical health indicators, suggesting that playful, tactile water experiences are linked to higher levels of physical engagement compared with passive, ornamental water features. This finding aligns with existing literature indicating that direct interaction with water is associated with reduced stress and increased activity among preschoolers.

Analysis of IPMA results indicates that water elements, such as ground-level fountains and interactive water puddles, have a notably positive effect on physical health, suggesting that hands-on water play is more beneficial than purely decorative features. This finding aligns with Thompson Coon et al. [7], who demonstrated that outdoor physical activities near natural waterscapes intensify children’s physical engagement.

Plant indicators were positively associated with measures of physical health and social adaptation. Children benefit from aesthetic, sensory, physical, and social interactions with plants, supporting environmental psychology theories that highlight the role of green spaces in promoting social cohesion and physical health [78]. The present analysis further identifies “biodiversity landscapes” and “real plant specimens” as having the highest relative importance among plant indicators, aligning with previous research on the value of authentic greenery in diversifying children’s sensory and exploratory behaviors.

Animal-related indicators showed significant associations with mental health and social adaptation. Animal companions help reduce anxiety and loneliness while also teaching children responsibility and empathy [79]. This reinforces the biophilia hypothesis, which suggests an innate human affinity for living things [80,81]. From IPMA analysis, “live, harmless animals” and “feeding/breeding areas” were the animal variables most strongly associated with mental well-being and prosocial behaviours, indicating that interactive animal experiences may have a stronger relationship than passive observations of specimens.

These results also reaffirm the biophilia hypothesis [82], underlining humanity’s inherent affinity for living organisms. In particular, the IPMA data highlight “live, harmless animals” and “feeding/breeding areas” as pivotal for promoting empathy and reducing anxiety, surpassing passive observations of animal specimens.

Ecosystem landscape indicators exhibited broad positive associations across all health and well-being measures. These multisensory environments provide diverse stimuli that support holistic cognitive and emotional growth. The present study contributes new evidence by showing that a multiplicity of natural elements (soil, rocks, water, and varied plantings) is associated with deeper creative play, better emotional regulation, and improved social cohesion in kindergarten settings.

These four elements embed fractal and symmetrical visual patterns—branching streams, leaf venation, animal coat motifs—that laboratory studies link to lowered physiological stress and enhanced attentional capacity in children [38–40]. This visual-complexity mechanism provides an additional explanation for the psychological and social gains observed, although fractal geometry itself was not quantified here.

Additionally, cultural considerations are critical in BD for early childhood education. In Chinese kindergartens, traditional values often emphasise collective stewardship and harmony with nature [83], potentially increasing acceptance of elements such as communal water play features or group gardening activities. Conversely, some Western contexts may prioritise wildlife habitats or individual interactions with nature, reflecting different cultural norms. By comparing these results to earlier investigations, the comprehensive framework proposed in this study (Table 9) prioritises specific biophilic interventions according to their performance and feasibility. This approach directly informs decision-making, ensuring practical guidelines that can be swiftly implemented in existing educational facilities, thus bridging empirical evidence and actionable strategies.

**Table 9.** Summary of significant indicators for BD elements and their impact on children’s health and well-being.

|    | Indicator | Description                                     | Physical Rank | Mental Rank | Social Adaptation Rank |
|----|-----------|-------------------------------------------------|---------------|-------------|------------------------|
| H1 | WA1       | Aquarium                                        | 4             | 4           | 4                      |
|    | WA2       | Miniature fountain                              | 2             | 2           | 2                      |
|    | WA3       | Outdoor ground-level fountain                   | 3             | 3           | 3                      |
|    | WA4       | Water puddle (for play)                         | 1             | 1           | 1                      |
| H2 | PL1       | Flower pots in the classroom                    | 2             | 2           | 2                      |
|    | PL2       | Biowall in the classroom                        | 5             | 5           | 5                      |
|    | PL3       | Biodiversity landscapes around the kindergarten | 1             | 1           | 1                      |
|    | PL4       | A view of landscapes from windows               | 6             | 6           | 6                      |
|    | PL5       | Planting greenery in platforms                  | 7             | 8           | 7                      |
|    | PL6       | Greenery into semi-enclosed school corridors.   | 4             | 4           | 4                      |
|    | PL7       | Real plant specimens                            | 3             | 3           | 3                      |
|    | PL8       | Greening roof                                   | 8             | 7           | 8                      |

Table 9. *Cont.*

|    | Indicator | Description                                     | Physical Rank | Mental Rank | Social Adaptation Rank |
|----|-----------|-------------------------------------------------|---------------|-------------|------------------------|
| H3 | AN1       | Live, harmless animals                          | 1             | 1           | 1                      |
|    | AN2       | Animal specimens                                | 3             | 3           | 3                      |
|    | AN3       | Feeding and breeding areas                      | 2             | 2           | 2                      |
| H4 | EC1       | Planting plants or crops                        | 1             | 1           | 1                      |
|    | EC2       | Path obstacles children pass through            | 2             | 2           | 2                      |
|    | EC3       | Increasing soil, rocks, etc., in limited spaces | 3             | 3           | 3                      |
|    | EC4       | Natural elements in activity areas.             | 3             | 4           | 4                      |

## 5. Conclusions

The PLS-SEM method used in this study illustrates the connection between biophilic environments in kindergartens and children’s health and well-being. The research findings strongly support the multiple benefits of integrating BD into these early childhood learning environments. Crucially, this study also presents new insights into which design interventions hold the greatest potential: interactive water features were most strongly associated with physical health indicators, live animal interactions with mental well-being, and multi-layered plant ecosystems for promoting social adaptation.

While existing studies acknowledge the benefits of nature in education, this research advances understanding by explicitly ranking biophilic elements according to their observed effect sizes and IPMA across distinct developmental domains (physical, mental, and social). Because the evidence derives from four case-study kindergartens in Henan Province, these quantitative results should be interpreted as exploratory and context-specific rather than nationally representative. Kindergartens that incorporate natural elements significantly improve children’s physical, mental, and social development within similar cultural and spatial conditions. Moreover, the large-scale application of PLS-SEM in this study provides empirical rigor and quantification rarely seen in kindergarten-focused research. By comparatively analyzing effect sizes across multiple biophilic elements, this research adds granularity to the widely accepted notion that “nature is beneficial”, offering clear guidance on prioritising natural interventions according to their relative impacts and local cultural acceptance.

The comprehensive framework presented herein synthesises empirical findings into actionable design recommendations, explicitly demonstrating how identified high-impact elements can feasibly and quickly be integrated into existing kindergarten environments. Educational policymakers and architects should include these principles in kindergarten designs to create healthier, more engaging environments for children. Any extrapolation to other provinces or countries should, however, be preceded by additional validation studies to account for regional differences in culture, climate, and resources. The research underscores the importance of shifting educational environment design towards nature integration to promote healthier, happier, and more socially cohesive generations.

### *Limitations and Future Directions*

A key limitation of this study is its focus on kindergartens in a single region, which may not fully capture the diversity of geographical and cultural contexts. Consequently, the quantitative deductions reported here are best viewed as preliminary and exploratory. To enhance the generalisability of the findings, future studies should include a broader range of locations and populations.

Additionally, this cross-sectional study does not account for the long-term effects of biophilic architecture on children’s development. Longitudinal studies are needed to understand how biophilic environments influence child development over time. Further-

more, while parent and teacher assessments were used to gauge children's health and well-being—after confirming that their preferences aligned with those of the children—these self-report ratings may contain perceptual bias. Because the analysis is based on subjective questionnaire data rather than medical or observational measures, the results show statistical associations rather than clinical causation. Future work could, where feasible, enrich self-report information with objective indicators of stress regulation or cognitive performance to strengthen these exploratory links. Thus, future research should employ longitudinal designs and objective health assessments to confirm the long-term effects of BD on child development and reduce potential bias.

Another limitation is the lack of subgroup analysis by socio-economic status (SES) or kindergarten types (e.g., urban vs. rural, private vs. public). Different SES backgrounds might yield varying attitudes or resource availability for biophilic design. Expanding the dataset across multiple provinces and kindergarten categories would also permit a mixed-methods approach, enabling richer qualitative insights to complement the exploratory quantitative findings. Future studies could stratify samples by these criteria to explore whether the outcomes differ in more affluent versus less affluent settings, thereby refining recommendations for diverse kindergarten contexts.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/buildings15091548/s1>, Supplementary 1: Implementation of Biophilic Design Elements in Kindergartens, Source: Adopted from (Huizi et al., 2024); Supplementary 2: Health Benefits of Biophilic Design in Various Domains, Source: adopted from (Huizi et al., 2024); Supplementary 3: For Parents and Teachers; Supplementary 4: Outer loading of Pilot study; Supplementary 6: Validity and reliability of measurement model; Supplementary 7: Discriminant validity (Cross-loading Matrix); Supplementary 8: Collinearity assessment (VIF Statistics) [84–131].

**Author Contributions:** Conceptualization, H.D. and M.A.I.; methodology, H.D. and R.S.; software, H.D. and R.S.; validation, H.D., M.A.I. and R.S.; formal analysis, H.D. and M.A.I.; investigation, H.D.; resources, H.D.; data curation, H.D.; writing—original draft preparation, H.D.; writing—review and editing, M.A.I. and R.S.; visualization, H.D.; supervision, M.A.I. and R.S. All authors have read and agreed to the published version of the manuscript.

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**Informed Consent Statement:** Written informed consent was obtained from all participants involved in the study. For children participants, written consent was obtained from their parents or legal guardians prior to the administration of the questionnaire. Teachers and parents participating in the survey provided written informed consent directly.

**Data Availability Statement:** Data are included in the article/Supplementary Material.

**Conflicts of Interest:** The authors declare that they have no competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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