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Spatial Configuration of Kindergarten Indoor Activity Spaces and Children's Embodied Behaviors: Evidence from Three Cases in Cold-Arid Western China

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Abstract

The paradigm shift in early childhood education from custodial care to development-centered environments underscores the importance of kindergarten indoor activity spaces. However, how spatial configuration influences children's embodied behaviors remains underexplored, particularly in cold-arid regions of western China, where prolonged indoor periods amplify the significance of interior spatial quality. Integrating embodied cognition and affordance theories, this study develops a coupling framework linking spatial metrics with behavioral outcomes. A mixed-methods approach combined 196 parent and 36 teacher questionnaires with space syntax analysis across three typical kindergartens in Lanzhou, China. Visual Integration [HH] was positively correlated with physical movement ($r = 0.52$, $p < 0.01$) and negatively correlated with solitude ($r = -0.52$, $p < 0.01$); Connectivity was positively associated with sensory exploration ($r = 0.42$, $p < 0.05$). Coupling coordination degrees ranged from 0.689 to 0.856, revealing a "high coupling, imbalanced development" pattern, with privacy affordance as a notable shortfall in the wide-corridor typology. The older courtyard-style kindergarten surpassed the newly built one (0.856 vs. 0.838) despite lower facility quality. Parent satisfaction depended more on spatial richness ($r = 0.61$) than on facility quality ($r = 0.47$). Spatial configuration shapes embodied behaviors through layout-specific affordances. An evidence-based optimization framework is proposed for kindergarten design in cold-arid climate zones.

Keywords: affordance; coupling coordination; embodied cognition; indoor spaces; kindergarten; space syntax

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1. Introduction

The paradigm shift in early childhood education has fundamentally transformed the role of kindergarten environments. Once conceived primarily as custodial facilities designed to ensure basic safety and daily routines, kindergartens are now expected to function as dynamic, development-centered settings that actively support children's cognitive, social, emotional, and physical growth [1]. According to national statistics, the gross enrollment rate for three-year preschool education in China reached 91.1% in 2023, with over 47 million children enrolled nationwide, making kindergarten design a critical focus of educational infrastructure development [2].

The strategic planning of educational infrastructure is increasingly recognized as a core component of sustainable smart city development. As cities evolve towards intelligent and resilient systems, the management of urban services—including the siting, design, and quality of early childhood education facilities—directly influences long-term social sustainability and human capital formation [3]. This perspective aligns with broader interdisciplinary calls to integrate legal, urban, and educational planning frameworks, ensuring that the built environment for young children receives systematic attention within urban development strategies [4]. Within such integrated frameworks, the micro-level design of children's daily spaces—the very settings where human capital formation begins—demands the same systematic rigor. Specifically, in cold-arid western China, prolonged indoor occupancy during harsh winters shifts the developmental burden onto interior spaces, amplifying the significance of spatial quality. Yet, despite children spending 8–10 h daily indoors [5–7], how spatial configuration influences their embodied behaviors in this climate remains critically underexplored.

To understand this underexplored mechanism, embodied cognition theory provides a foundational lens. The traditional cognitivist model, which treats cognition as abstract symbol manipulation detached from bodily experience, has been progressively challenged by evidence that cognitive processes are fundamentally grounded in sensorimotor interactions with the physical environment [8,9]. This view is supported by extensive theoretical and empirical work demonstrating that cognition is shaped by bodily states and situated actions [10–13]. For preschool children especially, whose cognitive development remains predominantly sensorimotor and concrete-operational in the Piagetian framework [14], the body serves as the primary medium through which they explore, understand, and construct meaning from their surroundings [15,16]. This recognition has elevated the importance of indoor activity spaces in kindergartens—as environments that afford physical movement, social interaction, sensory exploration, and solitary retreat [17,18].

Indoor activity spaces have emerged as the most significant learning environments in kindergartens, particularly in climatically constrained regions where outdoor play is frequently interrupted. However, traditional kindergarten designs, which prioritize classroom efficiency, standardized furniture arrangements, and linear circulation, often fail to accommodate the diverse and flexible embodied behaviors that are essential for healthy child development [19]. The structural mismatch between "spatial supply" and "embodied behavioral demand" has become increasingly pronounced in both research and practice [20].

From an architectural perspective, indoor activity space design in kindergartens faces three interrelated challenges. First, functional versatility requires spaces that simultaneously accommodate group activities, individual exploration, vigorous physical movement, and quiet retreat, demanding sophisticated spatial zoning and the creation of diverse micro-environments [21]. Second, spatial connectivity—encompassing visual accessibility, physical reachability, and configurational centrality—directly affects how children navigate, congregate, and disperse within the building [22,23]. Third, sensory richness—including the material, textural, chromatic, and morphological variety of the environment—has emerged as a critical determinant of children's exploratory engagement and place attachment [24,25].

Recent years have witnessed growing scholarly attention to the relationship between physical environments and children's behavior in early childhood settings. Van Liempd et al. [26] investigated how indoor play space characteristics in center-based childcare influenced young children's exploration, revealing systematic relationships between spatial features—floor surfaces, activity corners, and table configurations—and the depth and breadth of children's exploratory behaviors. Their study, grounded in embodied cognition and affordance theory, demonstrated that distinct spatial components generated characteristic behavioral profiles. Berris and Miller [27] examined how the physical design of early childhood education environments affected children's learning and development, identifying spatial layout, noise levels, and the availability of private spaces as key environmental factors. Berti et al. [28] employed children's drawings and interviews to capture how young children represent their early childhood education spaces, revealing that children perceive and value spatial features—hiding places, large open areas, and nature-connected elements—that are often overlooked in adult-centric evaluations.

From a methodological perspective, space syntax has emerged as a powerful analytical tool for quantifying spatial configuration and predicting patterns of movement and co-presence [29,30]. Although space syntax has been extensively applied to urban public spaces, museum layouts, and school buildings [31,32], its application to kindergarten indoor spaces remains limited. Kaya and colleagues [33] employed space syntax to analyze how spatial configuration influences children's spatial expectations in a natural playground designed through participatory processes, demonstrating that integration and connectivity values are closely linked to children's behavioral patterns. Jia et al. [34] investigated the impact of spatial configuration on evacuation efficiency in Chinese kindergarten activity units, demonstrating the broader applicability of configurational analysis to kindergarten building research. These studies collectively suggest that space syntax can reveal spatial properties—notably visual integration and connectivity—that are not discernible through traditional architectural description alone, yet may significantly shape how children use and experience space.

A recent systematic review by researchers in environmental psychology [35] examined the evidence linking spatial characteristics of early childhood education and care environments to children's behavior and development, concluding that spatial layout, the availability of private spaces, and the organization of activity areas are consistently associated with children's social interaction, physical activity, and exploratory behavior. Their review further highlighted that the majority of existing studies are concentrated in Western European and North American contexts, with a notable scarcity of empirical research from Asian settings, particularly from climatically distinct regions of western China [36–38].

Despite this growing body of research, the synergistic relationship between objective spatial metrics—particularly those derived from space syntax—and subjectively reported behavioral outcomes in kindergarten settings has received insufficient empirical attention, particularly in the cold-arid regions of western China. Under such climatic conditions, prolonged indoor occupancy increases the developmental significance of interior spatial quality, yet the coupling between spatial configuration and children's embodied behaviors remains critically underexamined. To address this gap, this study introduces a multi-dimensional coupling framework integrating space syntax analysis with teacher and parent questionnaires, and employs coupling coordination degree modeling to evaluate the alignment between spatial configuration and children's embodied behaviors across three typical kindergartens in Lanzhou. Specifically, the study aims to clarify how different indoor layout typologies—wide-corridor, courtyard, and linear layouts—generate distinct affordance profiles for children's physical movement, social interaction, sensory exploration, and solitude, thereby providing evidence-based implications for kindergarten indoor space design in cold-arid regions.

1.1. Kindergarten Indoor Activity Spaces

Kindergarten indoor activity spaces are defined as the physical environments within kindergarten buildings—outside formal classrooms—where children engage in self-directed and teacher-guided embodied activities [17,18]. In the context of Chinese kindergartens, indoor activity spaces encompass wide corridors, multi-purpose halls, reading corners, construction zones, art areas, and transitional spaces that connect standard classrooms. Three characteristic features distinguish indoor activity spaces from formal classroom settings: (1) functional versatility—the same space must accommodate multiple activities, including group games, individual exploration, vigorous physical movement, and quiet solitary retreat [39]; (2) user autonomy—children exercise a degree of choice over their activities, partners, and spatial locations, requiring environments that support diverse behavioral patterns [40]; and (3) developmental responsiveness—the spatial environment must be attuned to the sensorimotor and concrete-operational cognitive stage of preschool children aged 3–6 years, whose primary mode of engaging with the world is through bodily action rather than abstract symbolic manipulation [14,15].

1.2. Multi-Dimensional Coupling Theory and Analytical Framework

The concept of "coupling" originated in systems theory and refers to the mutual interaction and joint functioning of two or more systems [40]. In the context of architectural space, coupling describes the synergistic relationships among multiple dimensions that collectively shape user experience. Adapting this concept to kindergarten space research, this study proposes that indoor activity space optimization entails not a linear improvement of individual architectural elements but a synergistic process involving the co-evolution of multiple systems [41]. Specifically, four coupling relationships are identified: (1) space–behavior coupling—physical spatial configurations shape children's embodied behaviors, while evolving behavioral patterns drive spatial adaptation [41,42]; (2) layout–affordance coupling—distinct spatial layout typologies generate characteristic profiles of behavioral affordances, with wide corridors affording running, courtyards affording sensory exploration, and small nooks affording solitary retreat [23,25]; (3) teacher–parent perception coupling—teachers, as daily observers of children's behavior, and parents, as recipients of children's behavioral feedback at home, provide complementary perspectives on whether a space effectively supports children's embodied development [39]; and (4) facility–richness coupling—physical facility quality and perceived spatial richness represent distinct but interacting dimensions of environmental evaluation, with the latter potentially compensating for deficiencies in the former, as may occur in older courtyard-style kindergartens [35].

The novelty of the multi-dimensional coupling framework lies not merely in listing these dimensions but in emphasizing the interactions among them. For example, Visual Integration [HH] affects children's physical movement partly through its influence on perceived spatial openness, and the courtyard layout moderates the effect of facility condition on behavioral engagement. These interaction effects are captured by the coupling coordination degree model and the correlation analysis presented in Sections 3 and 4.

Based on these coupling relationships and a synthesis of prior research [19,27,28], this study develops a three-dimensional analytical framework for kindergarten indoor activity space evaluation: spatial configuration, embodied behavior, and parent satisfaction.

1.3. Embodied Cognition and Affordance Theory

Embodied cognition theory, originating in cognitive science and developmental psychology, provides a foundational framework for understanding how spatial characteristics influence children's behavioral and developmental outcomes [8,9]. According to this theory, cognitive processes are fundamentally grounded in the body's sensorimotor interactions with the physical environment, challenging the traditional Cartesian separation of mind and body [10,11]. For preschool children, whose cognitive development remains predominantly sensorimotor and concrete-operational within the Piagetian framework [14], the body serves as the primary medium of learning and meaning-making [15]. Affordance theory, originating in ecological psychology, provides the conceptual mechanism linking spatial features to behavioral possibilities [43]. As originally formulated by Gibson [44], an affordance refers to what the environment offers, provides, or furnishes the individual—whether for good or ill [45]. In the context of kindergarten indoor activity spaces, this theory suggests that children experience greater behavioral engagement and developmental benefit when spatial attributes align with their embodied action capabilities and developmental needs [26].

1.4. Research Hypotheses and Theoretical Model

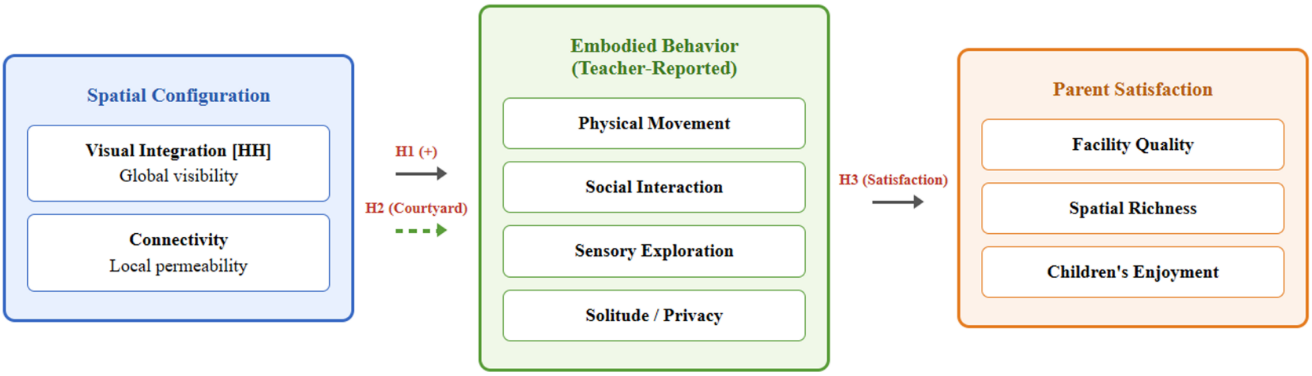
Based on the multi-dimensional coupling framework and embodied cognition–affordance theory, this study proposes three research hypotheses:

Hypothesis 1 (H1). *Visual Integration [HH] is positively associated with teacher-reported frequencies of children's physical movement, while Connectivity is positively associated with social interaction and sensory exploration behaviors in kindergarten indoor activity spaces.*

Hypothesis 2 (H2). *In the older courtyard-style kindergarten, the courtyard functions as a compensatory spatial node. Its spatial profile—characterized by moderate Visual Integration [HH] and high local Connectivity around the courtyard perimeter—is positively associated with sensory exploration and solitude behaviors, compensating for the lower facility quality ratings characteristic of this older facility.*

Hypothesis 3 (H3). *Parent satisfaction is more strongly associated with perceived spatial richness than with facility quality alone, and is positively associated with teacher-reported frequencies of children's embodied behaviors.*

The theoretical model integrating these hypotheses is presented in Figure 1.



Note: Solid arrows denote hypothesized positive effects; the dashed arrow for H2 indicates the compensatory courtyard mechanism.

Figure 1. Theoretical model and hypothesized relationships (by authors).

2. Materials and Methods

2.1. Study Sites

Three representative kindergartens in Lanzhou, China, were selected as research sites: Lanzhou University of Technology Kindergarten (LUT, a newly built public kindergarten), Northwest Normal University Kindergarten (NWNU, an older courtyard-style public kindergarten), and Huizhi Boren Kindergarten (Huizhi, a private linear-layout kindergarten). These kindergartens exhibit distinct characteristics in spatial layout, building age, and operational model, providing a comprehensive picture of kindergarten indoor activity space development in western China. All three kindergartens are located in urban Lanzhou and share similar climatic conditions (cold, dry winters and mild summers, with frequent spring sandstorms) and cultural contexts, thereby enhancing comparability. Table 1 summarizes the key characteristics of each case. The functional zones and spatial organization of each kindergarten are schematically illustrated in Figure 2. Ancillary spaces not accessible to children (e.g., offices, kitchens, storage rooms) are excluded from the annotation.

Table 1. Basic information of the three case kindergartens (by authors).

Feature	LUT	NWNU	Huizhi
Type	Public, newly built	Public, old	Private
Year established	2025	1939	2017
Layout type	Fishbone/Wide corridor	Courtyard enclosure	Linear (Single Corridor)
Ground floor indoor area (m^2)	2015	1340	1380
Number of classes	12	12	15
Climate adaptation	Central corridor for winter activity	Enclosed courtyard as buffer space	Internal corridor only

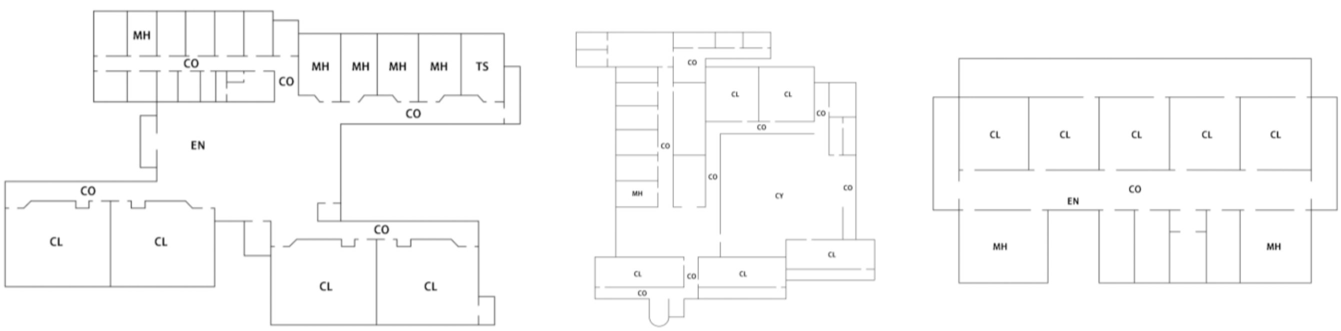


Figure 2. Annotated floor plans of the three case kindergartens. (**Left**) LUT (Fishbone). (**Center**) NWNU (Courtyard). (**Right**) Huizhi (Linear). CL = Classroom; CO = Central Open Space; MH = Multi-purpose Hall; TS = Transitional Space; CY = Courtyard; EN = Entrance Hall (by authors).

2.2. Spatial Analysis: Space Syntax

Space syntax analysis was conducted to quantify the spatial configuration characteristics of the three kindergartens. Floor plans of each kindergarten were obtained from the respective institutions and redrawn in AutoCAD 2020 to extract the spatial envelope, covering all indoor areas including classrooms, corridors, multi-purpose halls, and transitional spaces. The cleaned floor plans were then imported into Depthmap X 0.8.0 for analysis following standard VGA procedures [46].

A Visibility Graph Analysis (VGA) approach was adopted, given that the study concerns single-level indoor layouts where visual accessibility—rather than axial route structure—is the primary configurational property shaping children's spatial experience and behavioral choices. A grid of 0.5 m × 0.5 m was applied to approximate the average step length and body width of preschool children aged 3–6 years, ensuring that the spatial analysis reflects children's scale rather than adult norms. The following space syntax metrics were calculated for each kindergarten: Connectivity, which measures the number of immediate neighbors directly linked to each spatial unit and reflects local permeability and route options. In practical terms, high Connectivity means a child has many adjacent spaces to move into within a few steps, encouraging exploratory wandering and social encounters; Visual Integration [HH], which measures how easily a space can be seen from all other parts of the configuration and serves as the primary measure of spatial centrality. Practically, high Visual Integration makes a space visually accessible from many other areas, promoting running and group activities but limiting opportunities for privacy or quiet retreat. Given that the analyzed floor plans are single-level layouts, Visual Integration provides an equivalent measure of configurational centrality, exhibiting a strong correlation with axial integration in compact building interiors.

The entire indoor floor plan of each kindergarten was included in the VGA. This comprehensive approach preserves the configurational integrity of the spatial system, as visual and physical connections between classrooms and shared activity areas jointly constitute the spatial environment that children navigate daily. For each kindergarten, mean values and standard deviations of both metrics were computed across all grid cells within the indoor floor plan.

It should be noted that the space syntax metrics are used as objective measures of spatial potential. The actual behavioral engagement afforded by these spatial properties is examined through the teacher-reported questionnaire data and the coupling analysis presented in Sections 4.2 and 4.3.

2.3. Questionnaire Survey

2.3.1. Instrument Development

Two structured questionnaires were developed based on a review of the literature [19,26,27] and expert consultation: a Teacher Embodied Behavior Questionnaire and a Parent Satisfaction Questionnaire.

The Teacher Embodied Behavior Questionnaire comprised three sections: (1) demographic information (teaching experience, class level); (2) embodied behavior perception, consisting of 16 items measuring four dimensions—physical movement, social interaction, sensory exploration, and solitude; and (3) open-ended comments on spatial strengths and limitations. All items were rated on a 5-point Likert scale (1 = almost never observed, 5 = very frequently observed).

The Parent Satisfaction Questionnaire comprised three sections: (1) demographic information (child's age, class level, duration of enrollment); (2) satisfaction evaluation, consisting of 12 items measuring three dimensions—facility quality, spatial richness (defined as the perceived variety of spatial forms, activity zones, materials, and visual interest, and the diversity of behavioral affordances they support within the indoor environment), and children's enjoyment; and (3) open-ended comments. All items were rated on a 5-point Likert scale (1 = very dissatisfied, 5 = very satisfied).

To minimize common method bias, reverse-scored items were incorporated for approximately 20% of the questions across both questionnaires, and the order of items was randomized. Three experts in architecture, early childhood education, and developmental psychology reviewed the initial item pools. Pilot tests were conducted prior to formal data collection (n = 15 for the teacher questionnaire, n = 40 for the parent questionnaire) to refine item wording and confirm scale reliability.

2.3.2. Participants and Procedure

Data collection was conducted from October to December 2025. For the parent survey, stratified random sampling was employed, with questionnaires distributed proportionally across class levels within each kindergarten. For the teacher survey, all full-time teachers who spend complete working days with children were invited to participate. Questionnaires were distributed in paper form with the assistance of kindergarten administrators and collected by the research team within one week.

A total of 232 questionnaires were distributed, yielding 196 valid parent responses (response rate: 86.7%) and 36 valid teacher responses. Of the parent respondents, 52.6% were female and 47.4% were male, reporting on their children; 62.8% of the children were enrolled in middle or senior classes (aged 4–6 years), and 37.2% in junior classes (aged 3–4 years). All teacher respondents were female, with teaching experience ranging from 2 to 18 years (M = 7.4, SD = 4.6). The questionnaire sample distribution across the three kindergartens is presented in Table 2.

Table 2. Questionnaire sample distribution (by authors).

Case	Teachers (n)	Parents (n)	Total	Response Rate
LUT	15	78	93	88.6%
NWNU	12	64	76	86.5%
Huizhi	9	54	63	84.4%
Total	36	196	232	86.7%

2.4. Ethical Considerations

This study consisted of a non-interventional questionnaire survey. All participants were informed regarding the purpose of the study and provided informed consent prior to participation. Data were collected anonymously, and no personal identifying information was recorded. In accordance with Chinese national regulations—specifically, the Measures for Ethical Review of Life Sciences and Medical Research Involving Human Subjects (2023)—this type of anonymous survey does not require formal ethics committee approval. All procedures were conducted in accordance with the Declaration of Helsinki.

2.5. Analytical Methods

Data analysis proceeded in three stages. First, descriptive statistics, reliability analysis, and one-way ANOVA were performed using SPSS 26.0. Cronbach's α coefficients were calculated to assess the internal consistency of each questionnaire dimension, with values exceeding 0.70 considered acceptable. One-way ANOVA was conducted to test for significant differences among the three kindergartens in terms of both space syntax metrics and questionnaire dimensions.

Second, Pearson correlation analysis was employed to examine the bivariate relationships of space syntax metrics (Connectivity and Visual Integration [HH]) with teacher-reported embodied behavior dimensions (Physical Movement, Social Interaction, Sensory Exploration, and Solitude). The correlation coefficient r was used to quantify the strength of linear association. Following Cohen's conventions, values of 0.10–0.29, 0.30–0.49, and ≥0.50 represent small, medium, and large effect sizes, respectively.

Third, a coupling coordination degree model was applied to quantify the synergistic development between spatial configuration and embodied behavior [45,47], as detailed in Section 2.6.

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2.6. Coupling Coordination Degree Model

Unlike regression or SEM, the coupling coordination degree model (CCDM) is designed to assess balanced development between two interacting subsystems—here, spatial configuration and embodied behavior. This approach is particularly suitable given that regression assumes unidirectional causality and SEM typically requires large samples (N > 200), neither of which fits this study's conceptualization of mutual influence nor its sample size (N = 36 teacher-level observations). Unlike bivariate correlation analysis, which only captures linear association, CCDM reveals whether the two subsystems are developing at a mutually reinforcing level—a condition that cannot be inferred from correlation coefficients alone. Thus, CCDM serves as a more robust method for evaluating the spatial-behavioral gap across layout typologies [47,48].

First, data normalization was performed to eliminate dimensional differences between space syntax metrics and questionnaire scores:

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \quad (1)$$

where x_{ij} is the original value of indicator j for case i, and x'_{ij} is the normalized value ranging from 0 to 1.

Second, the entropy weight method was applied to determine the weight w_j of each indicator based on its degree of variation across cases. For each indicator, the information entropy (e_j) and redundancy ($g_j = 1 - e_j$) were calculated from the normalized values across the three kindergartens. The calculation steps and intermediate results are presented in Table 3. As shown in the table, Visual Integration received a higher weight (w = 0.58) than Connectivity (w = 0.42) because its redundancy (variation) was greater (0.116 vs. 0.084). The final weights for embodied behavior indicators were similarly determined. The comprehensive scores for spatial configuration (U_i) and embodied behavior (E_i) were then calculated:

$$U_i = \sum_{j=1}^{m} w_j \cdot x'_{ij} \quad (2)$$

$$E_i = \sum_{j=1}^{n} w_j \cdot x'_{ij} \quad (3)$$

where m and n denote the numbers of indicators in the spatial configuration and embodied behavior dimensions, respectively.

Table 3. Entropy weight calculation process for evaluation indicators (by authors).

Indicator Category	Indicator Name	Information Entropy (e_j)	Redundancy ($g_j = 1 - e_j$)	Weight (w_j)
Spatial Configuration	Connectivity	0.916	0.084	0.42
	Visual Integration [HH]	0.884	0.116	0.58
Embodied Behavior	Physical Movement	0.916	0.084	0.28
	Social Interaction	0.934	0.066	0.22
	Sensory Exploration	0.925	0.075	0.25
	Solitude	0.925	0.075	0.25

Third, the coupling degree C_i was computed:

$$C_i = \frac{2\sqrt{U_i \times E_i}}{U_i + E_i} \quad (4)$$

C_i ranges from 0 to 1, with higher values indicating stronger interaction between spatial configuration and embodied behavior.

Next, the comprehensive development index T_i was calculated:

$$T_i = \alpha U_i + \beta E_i \tag{5}$$

where α and β are weights reflecting the relative importance of each dimension. Consistent with the principle of balanced contribution, α and β were each set to 0.5.

Finally, the coupling coordination degree D_i was computed:

$$D_i = \sqrt{C_i \times T_i} \tag{6}$$

D_i integrates both coupling strength and development level, providing a comprehensive measure of system synergy. The coordination levels were classified following established conventions, as shown in Table 4.

Table 4. Classification criteria for coupling coordination degree (by authors).

D_i Range	Coordination Level
0.90–1.00	Excellent Coordination
0.80–0.89	Good Coordination
0.70–0.79	Intermediate Coordination
0.60–0.69	Primary Coordination
0.50–0.59	Barely Coordinated
0.00–0.49	Dysfunctional

3. Results

3.1. Spatial Configuration Analysis

Descriptive statistics and ANOVA results for the VGA-derived space syntax metrics are presented in Table 5. Visual Integration [HH] heatmaps are displayed in Figure 3, and Connectivity heatmaps in Figure 4.

Table 5. Descriptive statistics of space syntax metrics across the three kindergartens (by authors).

Metric	LUT (n = 8064)	NWNU (n = 5346)	Huizhi (n = 5530)	F	*p*
Connectivity	885.34 (287.46)	530.58 (128.35)	660.08 (141.92)	218.47	<0.001
Visual Integration [HH]	6.09 (1.18)	5.09 (0.97)	7.67 (1.56)	342.83	<0.001

Notes: n = the number of grid cells included in the VGA for each kindergarten. Standard deviations are shown in parentheses.

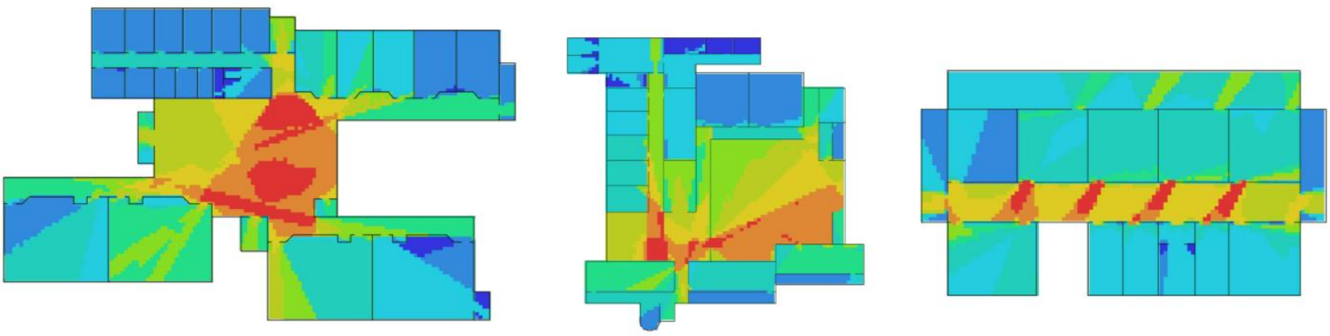

Figure 3. VGA heatmaps of Visual Integration [HH] for the three kindergartens. (**Left**) LUT (Fishbone). (**Center**) NWNU (Courtyard). (**Right**) Huizhi (Linear). Warmer colors indicate higher visual integration; cooler colors indicate lower visual integration (by authors).

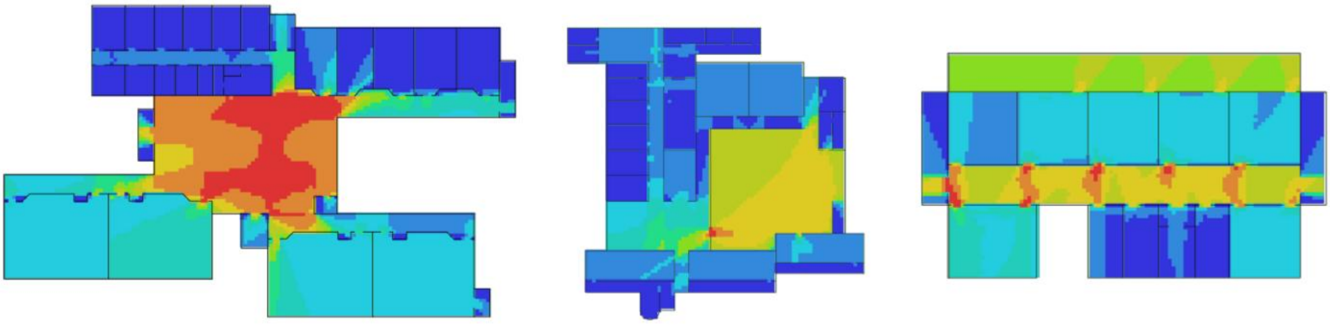

Figure 4. VGA heatmaps of Connectivity for the three kindergartens. (**Left**) LUT (Fishbone). (**Center**) NWNU (Courtyard). (**Right**) Huizhi (Linear). Warmer colors indicate higher connectivity; cooler colors indicate lower connectivity (by authors).

Both metrics showed highly significant differences across the three layout typologies ($p < 0.001$). Huizhi recorded the highest mean Visual Integration (M = 7.67, SD = 1.56), followed by LUT (M = 6.09, SD = 1.18) and NWNU (M = 5.09, SD = 0.97). LUT recorded the highest mean Connectivity (M = 885.34, SD = 287.46), followed by Huizhi (M = 660.08, SD = 141.92) and NWNU (M = 530.58, SD = 128.35). Notably, the courtyard perimeter of NWNU exhibited localized zones of elevated connectivity (see Figure 4), despite its lower overall mean.

3.2. Survey Results

Descriptive statistics for the teacher-reported embodied behavior dimensions and parent satisfaction dimensions are presented in Table 6. Cronbach's α coefficients for all dimensions ranged from 0.81 to 0.91, exceeding the recommended threshold of 0.70 and indicating good internal consistency.

Table 6. Mean scores (SD) of teacher-reported embodied behaviors and parent satisfaction across the three kindergartens (by authors).

Dimension	LUT	NWNU	Huizhi	F	*p*
Teacher-reported (n = 36)					
Physical Movement	4.13 (0.64)	3.92 (0.67)	2.89 (0.78)	8.76	0.004
Social Interaction	3.87 (0.72)	4.08 (0.51)	3.11 (0.93)	5.43	0.018
Sensory Exploration	3.33 (0.82)	4.17 (0.58)	2.78 (0.83)	10.21	0.002
Solitude/Privacy	2.47 (0.92)	4.25 (0.62)	3.22 (0.97)	14.35	<0.001
Parent-reported (n = 196)					
Facility Quality	4.41 (0.49)	3.08 (0.61)	3.72 (0.68)	18.12	<0.001
Spatial Richness	3.43 (0.71)	4.18 (0.53)	2.91 (0.79)	13.45	<0.001
Children's Enjoyment	3.92 (0.64)	4.29 (0.47)	3.34 (0.75)	10.28	<0.001

Notes: All items rated on 5-point Likert scales. Teacher scale: 1 = almost never observed, 5 = very frequently observed. Parent scale: 1 = very dissatisfied, 5 = very satisfied.

Overall, the descriptive results revealed clear differentiation among the three kindergartens. Among the teacher-reported dimensions, NWNU received the highest ratings on Sensory Exploration (M = 4.17) and Solitude (M = 4.25), while LUT scored highest on Physical Movement (M = 4.13). Huizhi recorded the lowest scores across all four behavioral dimensions. Among the parent-reported dimensions, LUT received the highest Facility Quality rating (M = 4.41), whereas NWNU received the highest ratings on Spatial Richness (M = 4.18) and children's Enjoyment (M = 4.29), despite its markedly lower Facility Quality score. All dimensions showed significant differences across the three kindergartens ($p < 0.05$).

3.3. Coupling Coordination Degree Analysis

To quantify the synergistic development between spatial configuration and embodied behavior, the coupling coordination degree model was applied. The comprehensive scores for spatial configuration (U_i), embodied behavior (E_i), coupling degree (C_i), comprehensive development index (T_i), and coupling coordination degree (D_i) for each kindergarten are presented in Table 7.

Table 7. Coupling coordination degree results by kindergarten (by authors).

Case	U_i	E_i	C_i	T_i	D_i	Coordination Level
LUT	0.892	0.613	0.933	0.753	0.838	Good Coordination
NWNU	0.647	0.898	0.948	0.773	0.856	Good Coordination
Huizhi	0.431	0.546	0.972	0.489	0.689	Primary Coordination

Notes: U_i = comprehensive score of spatial configuration (Connectivity and Visual Integration [HH] via the entropy weight method); E_i = comprehensive score of embodied behavior (four teacher-reported dimensions). C_i = coupling degree; T_i = comprehensive development index; D_i = coupling coordination degree.

The coupling coordination degrees ranged from 0.689 to 0.856, revealing a clear "spatial-behavioral gap" pattern. The older courtyard-style kindergarten (NWNU) achieved the highest coordination level (D = 0.856, Good Coordination), surpassing the newly built kindergarten (LUT, D = 0.838). Huizhi recorded the lowest coordination level (D = 0.689, Primary Coordination). The coupling degrees (C_i) ranged from 0.933 to 0.972, indicating strong interactions between spatial configuration and embodied behavior across all three cases. However, as illustrated in Figure 5, the three kindergartens exhibited markedly different structural profiles. The grouped bar chart compares U_i and E_i across the three cases, while the accompanying summary table reports all five coupling indicators. NWNU's profile was characterized by a pronounced behavioral advantage (E_i = 0.898) despite a lower spatial score (U_i = 0.647), resulting in the highest T_i (0.773). LUT showed the opposite pattern—a high spatial score (U_i = 0.892) accompanied by a moderate behavioral score (E_i = 0.613), reflecting a gap between spatial provision and behavioral actualization. Huizhi recorded low scores on both dimensions (U_i = 0.431, E_i = 0.546), yielding the smallest T_i (0.489) and the lowest D_i (0.689).

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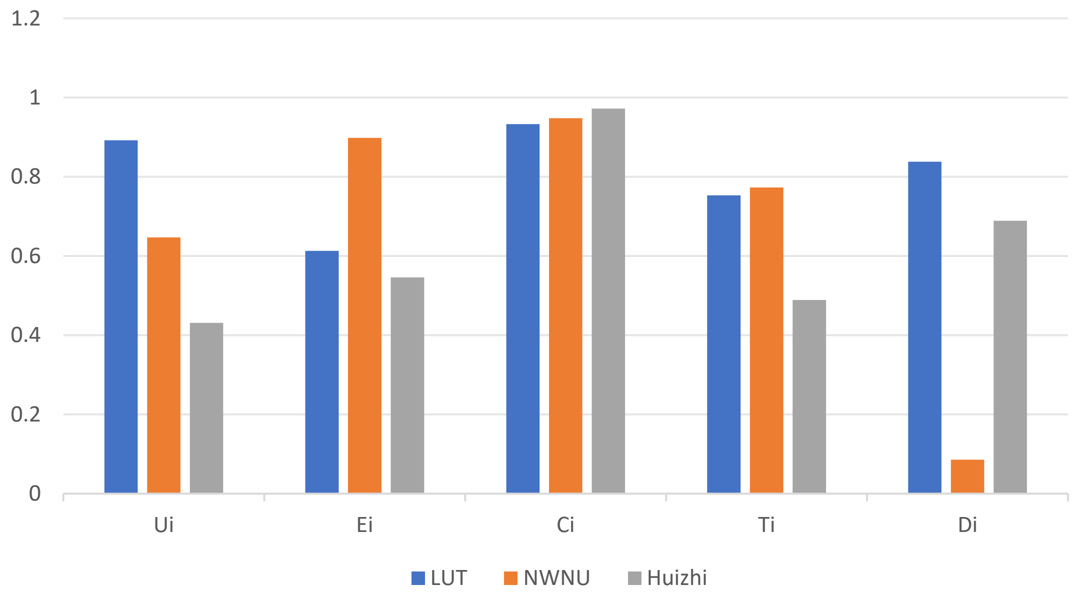

Figure 5. Comprehensive results of the coupling coordination degree analysis for the three kindergartens (by authors).

3.4. Correlation Analysis

Pearson correlation analysis was conducted to examine the bivariate relationships between space syntax metrics and teacher-reported embodied behavior dimensions. The correlation matrix is presented in Table 8.

Table 8. Pearson correlation matrix of space syntax metrics and embodied behavior dimensions (by authors).

	1	2	3	4	5	6
1. Visual Integration [HH]	1					
2. Connectivity	0.63 **	1				
3. Physical Movement	0.52 **	0.41 *	1			
4. Social Interaction	0.29	0.38 *	0.45 *	1		
5. Sensory Exploration	−0.37 *	0.42 *	−0.08	0.42 *	1	
6. Solitude/Privacy	−0.52 **	0.15	−0.31	0.15	0.56 **	1

Notes: * $p < 0.05$; ** $p < 0.01$. N = 36 (teacher-level analysis). Pearson correlation coefficients (r) are reported. Following Cohen's conventions, values of 0.10–0.29, 0.30–0.49, and ≥0.50 represent small, medium, and large effect sizes, respectively.

Visual Integration was significantly positively correlated with Physical Movement (r = 0.52, $p < 0.01$) and significantly negatively correlated with Solitude (r = −0.52, $p < 0.01$) and Sensory Exploration (r = −0.37, $p < 0.05$). Connectivity was significantly positively correlated with Sensory Exploration (r = 0.42, $p < 0.05$), Social Interaction (r = 0.38, $p < 0.05$), and Physical Movement (r = 0.41, $p < 0.05$). Visual Integration and Connectivity were positively correlated (r = 0.63, $p < 0.01$). In addition, among the parent satisfaction dimensions, Spatial Richness was more strongly associated with Children's Enjoyment (r = 0.61, $p < 0.01$) than was Facility Quality (r = 0.47, $p < 0.01$).

4. Discussion

This study investigated the relationship between spatial configuration and children's embodied behaviors in kindergarten indoor activity spaces, using a multi-dimensional coupling framework and empirical data from three typical kindergartens in Lanzhou, China. The findings reveal several important insights.

4.1. Spatial Configuration and Embodied Behavior: Evidence for H1

Visual Integration was significantly positively correlated with Physical Movement (r = 0.52, $p < 0.01$) and significantly negatively correlated with Solitude (r = −0.52, $p < 0.01$) and Sensory Exploration (r = −0.37, $p < 0.05$). These findings support H1 and are consistent with the theoretical expectation that visual accessibility generates divergent affordances for different types of embodied behavior. Spaces with high visual integration—such as the wide central corridor of LUT and the elongated corridor of Huizhi—provide unobstructed sightlines that afford running and vigorous movement. However, the same visibility simultaneously constrains behaviors that require shelter from observation, such as solitary retreat and absorbed sensory exploration. This dual effect—promoting movement while inhibiting retreat—represents a spatial tradeoff that has received little empirical attention in kindergarten design research. This finding aligns with Deng et al. [49], who identified that specific spatial affordances in classroom environments directly facilitate or constrain children's immediate physical actions during free play.

Connectivity showed a complementary pattern: it was positively associated with Sensory Exploration (r = 0.42, $p < 0.05$), Social Interaction (r = 0.38, $p < 0.05$), and Physical Movement (r = 0.41, $p < 0.05$). Unlike Visual Integration, which favors openness and visibility, Connectivity captures the local network of spatial choices. Spaces with high connectivity offer multiple routes and adjacent niches, which appear to encourage the kind of meandering, exploratory movement characteristic of sensory engagement. Taken together, these findings reveal a fundamental tradeoff inherent in kindergarten spatial design. The very properties that make a space conducive to vigorous movement and social congregation—high visual integration and open sightlines—simultaneously undermine the psychological conditions necessary for solitary retreat and absorbed sensory exploration. This tradeoff is not adequately captured by conventional design guidelines that prioritize spatial openness as an unqualified good. Similarly, Kyttä [35] found that high visual accessibility in children's environments facilitated social encounters but limited opportunities for privacy and retreat, reinforcing the generality of this spatial tradeoff across different cultural contexts.

4.2. The Courtyard as Compensatory Affordance: Evidence for H2

The coupling coordination analysis challenges conventional assumptions about the relationship between building quality and developmental affordances. NWNU, the oldest kindergarten with the lowest facility quality ratings (M = 3.08), achieved the highest coupling coordination degree (D = 0.856, Good Coordination), surpassing the newly built LUT (D = 0.838). This finding supports H2 and suggests that the courtyard typology generates compensatory affordances that offset deficiencies in physical infrastructure. This corroborates recent findings in the Chinese context [50], suggesting that well-designed outdoor environments significantly support children's autonomous play behavior. Similarly, Deng et al. [41] identified that the spatial affordances of Chinese kindergarten classrooms directly shape children's free-play actions.

As illustrated in the spatial analysis (Section 4.1), the NWNU courtyard perimeter exhibits localized zones of elevated connectivity where corridors, classroom doorways, and courtyard edges intersect. This configurational signature—high local connectivity coupled with moderate visual integration—creates a spatial environment that simultaneously affords exploration (through multiple route options) and shelter (through reduced visual exposure). Figure 5 captures this structural pattern succinctly: NWNU's behavioral score (E_i = 0.898) substantially exceeds its spatial score (U_i = 0.647), indicating that the behavioral affordances generated by the courtyard typology are not fully captured by standard space syntax metrics alone.

This "old but effective" paradox has practical implications. It suggests that renovation strategies for older courtyard-style kindergartens should preserve and enhance the configurational properties of the courtyard perimeter—the niches, edges, and transitional zones. These should be prioritized over the modernization of surface finishes. Conversely, the design of new kindergartens should not rely solely on spatial openness and wide corridors. The provision of visually sheltered micro-environments appears critical for supporting the full spectrum of children's embodied behaviors.

4.3. Parent Satisfaction and Perceived Spatial Richness: Evidence for H3

Parent satisfaction was more strongly associated with Spatial Richness (r = 0.61) than Facility Quality (r = 0.47), supporting H3. This finding is consistent with a recent study of forest kindergartens in Korea, which found that parents placed greater importance on safety and educational outcomes than on modern finishes, while children valued natural and play-oriented elements [51]. Similarly, Berti et al. [28] found that children's own drawings emphasized hiding places and nature-connected elements—features closely related to spatial richness rather than facility newness—suggesting that parents and children share a preference for affordance-rich spaces. This finding aligns with the broader environmental psychology literature on place attachment, which suggests that affective responses to environments are shaped by perceived behavioral possibilities rather than physical condition alone. Parents observe their children's behavioral and emotional responses over extended periods. They appear sensitive to whether a space is "working" for their child—whether it stimulates curiosity, enables physical exertion, and generates positive emotional responses.

The convergence between parent and teacher perceptions further strengthens this interpretation. NWNU, which received the highest teacher-reported scores on Sensory Exploration (M = 4.17) and Solitude (M = 4.25), also received the highest parent ratings on Spatial Richness (M = 4.18) and children's Enjoyment (M = 4.29). This convergence suggests that the behavioral affordances perceived by teachers—who observe children daily—are also detectable by parents through their children's behavioral feedback at home. This perceptual pathway represents a feedback loop that warrants further investigation. It extends from children's embodied experiences in kindergarten, to their post-school behavior and emotional expressions at home, and finally to parents' evaluative judgments of spatial quality. It implies that the 'end users' of kindergarten design are not only the children who directly inhabit these spaces, but also the families who observe their effects.

4.4. The Role of Corridor Space

The three kindergartens represent three distinct configurational strategies for corridor design, each generating a different profile of affordances. The wide central corridor of LUT functions as an activity spine that affords running and social congregation, consistent with its highest Physical Movement scores (M = 4.13). However, its high visual integration and lack of differentiated micro-environments provide few opportunities for retreat. The narrow linear corridor of Huizhi functions primarily as a circulation channel, with correspondingly low scores across all behavioral dimensions. The courtyard corridors of NWNU, by contrast, generate a rich edge ecology. The continuous alternation between open views into the courtyard and enclosed passage along the classroom walls creates a rhythmic spatial experience. This affords both social connection and momentary withdrawal.

This comparison suggests that corridor width is not the determining design parameter. Rather, the configurational role of the corridor—whether it functions as a spine, a channel, or an edge—determines the range of affordances it generates. Wide corridors that lack differentiated micro-environments may simply encourage undirected running, whereas corridors organized around courtyards may provide a richer repertoire of spatial experiences.

4.5. Implications for Kindergarten Design in Cold-Arid Climate Zones

The Lanzhou context gives these findings particular practical weight. During the long winter months (November through March) and frequent spring sandstorms, children's daily outdoor activity is severely curtailed, and indoor spaces become the primary setting for physical movement, social interaction, and sensory exploration. Under such conditions, the configurational properties of indoor spaces carry disproportionate significance in determining children's daily embodied experience.

Three evidence-based design strategies emerge from this study. First, new kindergartens in cold-arid regions should incorporate a variety of micro-environments—nooks, alcoves, and transitional spaces—along major circulation routes to support the full behavioral spectrum, rather than relying exclusively on wide, visually open corridors. Second, existing courtyard-style kindergartens should be recognized as possessing valuable configurational assets that no amount of surface modernization can replicate; renovation efforts should focus on enhancing the courtyard edge ecology. Third, kindergarten design guidelines should consider spatial connectivity indicators in addition to per-child area requirements, given that the former are more directly associated with the behavioral affordances that support healthy child development.

5. Conclusions

5.1. Summary of Key Findings

This study developed a multi-dimensional coupling framework integrating space syntax analysis with teacher and parent questionnaires to examine the relationship between spatial configuration and children's embodied behaviors in kindergarten indoor activity spaces. Drawing on empirical evidence from three typical kindergartens in Lanzhou, China, three principal findings emerged. A summary of the hypotheses and their supporting evidence is presented in Table 9.

Table 9. Summary of hypotheses and supporting evidence (by authors).

Hypothesis	Key Finding	Statistical Support
H1: Visual Integration [HH] → Physical Movement	Higher VI associated with more physical movement	r = 0.52, $p < 0.01$
H1: Visual Integration [HH] → Solitude/Privacy	Higher VI associated with less Solitude/Privacy	r = −0.52, $p < 0.01$
H1: Connectivity → Sensory Exploration	Higher connectivity associated with more sensory exploration	r = 0.42, $p < 0.05$
H2: Courtyard as compensatory affordance	The older courtyard typology demonstrated superior behavioral affordances compared to the newer wide-corridor typology	D = 0.856 (NWNU) vs. 0.838 (LUT)
H3: Spatial Richness vs. Facility Quality	Spatial richness more strongly predicts parent satisfaction	r = 0.61 vs. r = 0.47

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First, spatial configuration metrics were significantly associated with distinct dimensions of embodied behavior. Visual Integration was positively correlated with Physical Movement (r = 0.52, $p < 0.01$) and negatively correlated with Solitude/Privacy (r = −0.52, $p < 0.01$) and Sensory Exploration (r = −0.37, $p < 0.05$), while Connectivity was positively associated with Sensory Exploration (r = 0.42, $p < 0.05$), Social Interaction (r = 0.38, $p < 0.05$), and Physical Movement (r = 0.41, $p < 0.05$). These findings indicate that visual accessibility and local permeability generate functionally distinct affordances for children's embodied behaviors—affordances that may, at times, be in tension with one another.

Second, the coupling coordination analysis revealed a "spatial-behavioral gap" pattern. The older courtyard-style kindergarten (NWNU) achieved the highest coordination degree (D = 0.856, Good Coordination), surpassing the newly built kindergarten (LUT, D = 0.838), while the private linear-layout kindergarten (Huizhi) recorded the lowest (D = 0.689, Primary Coordination). The courtyard perimeter, characterized by moderate visual integration and high local connectivity, functioned as a compensatory spatial node that supported sensory exploration and solitary retreat despite lower facility quality.

Third, parent satisfaction was more strongly associated with perceived spatial richness (r = 0.61) than with facility quality (r = 0.47), and converged with teacher-reported behavioral outcomes. This suggests that parents are sensitive to whether a space affords diverse activities for their children, irrespective of its physical condition.

5.2. Theoretical Contributions

This study makes three theoretical contributions. First, it develops a multi-dimensional coupling framework that integrates objective spatial metrics (Connectivity, Visual Integration [HH]) with subjective behavioral data (teacher reports, parent satisfaction), thereby extending embodied cognition and affordance theory into the empirical study of kindergarten environments. Within this framework, "affordance" is operationalized as the statistical association between configurational properties and observed behavior frequency. Second, it provides empirical evidence for a courtyard compensatory mechanism. The finding that an older courtyard typology outperforms a modern wide-corridor layout on behavioral measures challenges the implicit assumption that newer facilities necessarily provide better developmental environments. Third, it demonstrates the utility of coupling coordination degree analysis as a quantitative tool for evaluating the alignment between spatial design and behavioral outcomes in educational settings.

5.3. Practical Implications

Based on the empirical findings, three evidence-based design strategies are proposed for kindergarten indoor activity spaces in cold-arid climate zones:

1. For new kindergartens: Wide corridors and high visual integration, while affording physical movement, should be complemented by a variety of micro-environments—nooks, alcoves, and transitional spaces—along major circulation routes. These differentiated spaces support the full behavioral spectrum, particularly sensory exploration and solitary retreat, both of which require visual shelter.

2. For existing courtyard-style kindergartens: Renovation efforts should preserve and enhance the configurational assets of the courtyard perimeter—the niches, edges, and transitional zones where corridors, classroom doorways, and courtyard edges intersect. Surface modernization should not come at the expense of spatial complexity.

3. For design standards: Kindergarten design guidelines in cold-arid regions should consider spatial connectivity indicators as a complement to per-child area requirements. The configurational properties of indoor spaces carry disproportionate weight during the long winter months when outdoor activity is severely curtailed.

5.4. Limitations and Future Research

Several limitations of the present study should be acknowledged. First, the sample was limited to three kindergartens in a single city; thus, the findings may not be fully generalizable to other climatic or cultural contexts. Second, the cross-sectional design precludes causal inference, and longitudinal or quasi-experimental studies are needed to determine whether spatial reconfiguration causally affects behavioral outcomes. Third, the teacher sample was modest (N = 36 across three kindergartens), which limits the statistical power for detecting small effect sizes ($r < 0.30$) and precludes more sophisticated multivariate techniques such as structural equation modeling or multilevel analysis. Fourth, embodied behavior data were collected through teacher reports rather than direct observation, which may introduce perceptual biases, such as overestimating salient behaviors like physical movement while underestimating quieter behaviors like solitude. Although the use of multiple teachers per kindergarten helped mitigate this to some extent, the correlation coefficients should be interpreted with caution. Fifth, the space syntax analysis was restricted to single-level VGA because the primary indoor activity spaces of the three kindergartens are concentrated on the ground floor; multi-level spatial analysis could provide a more complete understanding of spatial configuration in multi-story kindergarten buildings.

Future research should expand geographic coverage to include kindergartens in other climate zones, employ longitudinal or quasi-experimental designs to test the causal effects of spatial reconfiguration, and use larger teacher samples to confirm the robustness of the findings. Future studies should also incorporate direct behavioral observation, video analysis, or wearable sensor methods, and extend the space syntax analysis to multi-level configurations. Moreover, the moderating roles of pedagogical approach, teacher behavior, and daily activity organization in the space-behavior relationship warrant further investigation.

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Abbreviations

The following abbreviations are used in this manuscript:

ANOVA	Analysis of Variance
CCDM	Coupling Coordination Degree Model
HH	Hillier-Hanson (radius for global integration)
LUT	Lanzhou University of Technology Kindergarten
NWNU	Northwest Normal University Kindergarten
SD	Standard Deviation
SEM	Structural Equation Modeling
SPSS	Statistical Package for the Social Sciences
VGA	Visibility Graph Analysis

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