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Research Article

Universal Design in Montessori Kindergarten Design: Analysing The Benefits of Montessori Kindergarten Design for All Children

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Abstract

Educational inequality is a worldwide challenge, highlighting the need for alternative learning environments that provide equitable access and meaningful participation for diverse learners. Montessori is a well-established example of a developmentally beneficial approach, which is a model of the high-fidelity pedagogy, but requires accurate architectural translation. There is an important research gap due to the lack of an integrated architectural framework that systematically combines Montessori pedagogy (e.g., the Prepared Environment and Autonomy) with Universal Design principles, despite their strong theoretical synergy. This study employed a qualitative framework-development methodology based exclusively on secondary evidence, comprising a systematic literature review, secondary comparative architectural case study analysis, and design framework synthesis. The study did not involve primary data collection from users or experts; therefore, the proposed framework represents a theoretically and analytically derived model that requires further empirical validation. The main output is the Universal Montessori Kindergarten Design Framework (UMKDF), which has four verifiable layers: theoretical Inputs (Pedagogical and Accessibility principles); Spatial Translation Mechanisms (e.g., Kinetic Planning); a Design Control System (measurable architectural outputs); and a Risk Management Layer to mitigate functional failures like noise stress and accessibility breakdowns. The UMKDF provides a theoretically and analytically derived architectural framework for identifying and addressing key spatial conflicts between Montessori autonomy, universal accessibility, sensory regulation, and risk control. Its practical effectiveness requires further empirical validation through stakeholder evaluation and post-occupancy studies.

Keywords: Design Framework, Early Childhood Education, Inclusive Learning Environments, Montessori Architecture, Universal Design.

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INTRODUCTION

Addressing the global challenges of disability access and educational inequity requires a systematic re-evaluation of how early-childhood learning environments are conceived, designed, and organized. Traditional educational settings often locate learning difficulties within students rather than recognizing barriers embedded in curricula and physical environments (Ewe & Galvin, 2023; Bertling et al., n.d.). Universal Design for Learning (UDL) draws on the broader concept of Universal Design (UD) and applies inclusive-design principles to curriculum and instruction. It is a research-based framework that seeks to optimize learning by anticipating learner variability from the outset (Ewe & Galvin, 2023). UDL aims to reduce curricular barriers by creating equitable access and meaningful participation for diverse learners in early childhood settings (Bertling et al., n.d.; Rosati, 2021). Maria Montessori emphasized the pedagogical role of the physical environment in children's learning and development (Casha, 2015). According to longest-running alternative pedagogy globally since 1907. The Montessori prepared environment is intentionally organized to support children's independence, autonomy, and self-directed activity (Casha, 2015). Key features of Montessori include child-centred scaling of furniture and fixtures, freedom of movement, and self-correcting materials, which are structurally aligned with selected principles of UD (Rosati, 2021). Actually, the purposes of UD that concentrate on creating proper solution for all the necessities have been aspired from Montessori's design philosophy for an environment that fits the needs of all children (Rosati, 2021). In addition, in addition, a recent national randomized controlled trial (RCT) reported higher scores in reading, executive function, short-term memory, and theory of mind by the end of kindergarten among children attending public Montessori preschool (Lillard et al., 2025). Despite this clear theoretical synergy and demonstrated efficacy, a critical Montessori architectural gap persists. Researches on the cases of the Montessori facilities assume that there may be inadequateness and material deficiencies in Montessori-such as rigid forms, walled separations, or insufficient use of space that directly reduce the quality of education delivered (Khan & Ebrahimi, 2021).

Consequently, a major research gap is the lack of a formal, integrated model systematically merging high Montessori pedagogical fidelity with rigorous UD/ UDL mandates (Ewe & Galvin, 2023). The mentioned gap has been worsening by the critical lack of empirical research concerning UDL implementation in preschool and early years' education (Ewe & Galvin, 2023). This is used to prevent the designers from determining the optimal level of architectural fidelity required to maximize positive student outcomes (Lillard et al., 2025).

Therefore, this study is designed and created to empower develop the Universal Montessori Kindergarten Design Framework (UMKDF), presented here as a novel, systematic contribution. The UMKDF is to create measurable design outputs and operational checklists to alter the Montessori basics into global accessible architecture. There are different criteria that Composes the framework's concentration, such as kinetic and flexible zoning. Low furniture partitions, anthropometric detailing of all fixed elements and material strategies are used by this zoning that are used to enhance perceptible information (Casha, 2015; Hashimoto et al., 2025). Effectiveness and being highly cost-effective are from main features of UMKDF that intentionally accommodates higher child-to-teacher ratios (25+ children per class), which more than compensates for material costs and leads to substantial operational savings (Lillard et al., 2025).

This dual justification (educational efficacy and economic responsibility) validates the architectural optimization proposed. The theoretical foundations,

detailing the conceptual agreements and conflicts between Montessori and UD are detailed in the following. Consequently, it constructs the UMKDF which defines specific design outputs and necessary risk-control layers for the prevention of failures. The analysis concludes with a retrospective analytical assessment of the proposed framework, identifying critical assumption, research gaps and policy- level implications for inclusive educational architecture.

Accordingly, the aim of this study is to develop and analytically examine an architectural framework that systematically translates Montessori pedagogical principles and Universal Design requirements into spatial, dimensional, sensory, accessibility, and risk-control criteria for kindergarten environments. The study specifically seeks to: (1) identify the principal architectural correspondences and conflicts between Montessori pedagogy and Universal Design; (2) translate these principles into an integrated set of spatial organization, circulation, anthropometric, sensory, and risk-management requirements; and (3) retrospectively examine the analytical applicability of the proposed UMKDF through documented kindergarten case studies. The study is guided by the following research question: How can Montessori pedagogical principles and the seven Principles of Universal Design be systematically translated into an architectural framework that supports inclusive spatial organization, child autonomy, accessibility, sensory regulation, and safe use in kindergarten environments?

LITERATURE REVIEW

Montessori Pedagogy as the Foundation

Commitment to a structured set of spatial principles is the most important feature of Montessori (Casha, 2015). Prepared environment is the most critical foundational principle which is established by Maria Montessori as first proponent of a pedagogical physical environment (Casha, 2015). This meticulously managed structure is designed to support the child's physical and psychological development (Li & Zhao, 2023), transmitting values of self-activity and responsibility (Casha, 2015). The physical structure empowers an environment of a powerful order, often encapsulated by the motto: "everything in its place and a place for everything" (Rosati, 2021). Autonomy and independence is the principle of the prepared environment, which is foundational to the pedagogy (Hashimoto et al., 2025). A powerful learning environment that enables children to learn via free choice, discovery, hands on material and self-assessment must be encouraged and persuaded by self-directed activity. The mentioned activity is implemented without constant adult-intervention. (Lillard et al., 2025; Casha, 2015). The pedagogy of Montessori strongly relies on Sensorial Learning. This pedagogy of multi-sensory eases the essential cognitive acquisition of abstract concepts (Utami & Ishartiwi, 2025; Rosati, 2021). Self-correcting is the core of these moralizing and didactic materials that allow children to understand their mistakes instantly, reduce the need for teacher intervention, and nurture autonomy and resilience (Casha, 2015).

The Child-Centred Scaling is the foundational principle of architectural design (Pang et al., 2024). The facilities must be physically set with the needs of the children's small scale to indicate that the space is created for them (Casha, 2015). These adaptations aren't done but by lowering window sills, handrails, and sinks, while furniture must be light and movable so children can rearrange the space without assistance, reinforcing functional independence (Casha, 2015; Pang et al., 2024).

The Inclusion Framework: Universal Design and Universal Design for Learning (UDL)

The UDL provides an inclusive early childhood environment; it ensures an equitable access and effective attendance by flexible and creative approaches within a developmentally appropriate setting (Bertling et al., n.d.). Architectural translation of UD often involves incorporating features such as varied ramps and chutes to allow access whether children are standing or seated, supporting the principle of Equitable Use (Bertling et al., n.d.). The ability of the Montessori Method to offer multi-sensory materials directly supports the UDL principle of Multiple Means of Representation (Rosati, 2021). In addition, it's optional to select materials at a single pace that aligns with UDL's concentration on Engagement, fostering determination and persistence (Rosati, 2021).

In the present study, inclusivity is interpreted more broadly than physical accessibility or anthropometric scaling alone. Within the combined UD/UDL perspective, learner variability is considered across four interrelated domains: physical and mobility needs, sensory and perceptual needs, cognitive and learning variability, and emotional/self-regulatory needs. Physical and mobility inclusion requires barrier-free circulation, low physical effort, and child-scaled access to furniture and fixtures. Sensory and perceptual inclusion requires control of excessive acoustic stimulation together with clear, multi-sensory environmental information. Cognitive and learning inclusion requires flexible environments that support different modes of engagement and representation, while emotional and self-regulatory inclusion requires opportunities for both active communal participation and quieter retreat or individual concentration. These dimensions extend the framework beyond conventional accessibility and position inclusion as a multidimensional environmental requirement (Bertling et al., n.d.; Rosati,2021; Casha, 2015).

For terminological consistency, this study adopts the seven Principles of Universal Design (Version 2.0) established by the Center for Universal Design: (1) Equitable Use, (2) Flexibility in Use, (3) Simple and Intuitive Use, (4) Perceptible Information, (5) Tolerance for Error, (6) Low Physical Effort, and (7) Size and Space for Approach and Use (Center for Universal Design, 1997). These principles address the usability of products and environments for people with diverse abilities and are used in the UMKDF as the formal architectural accessibility reference. Universal Design for Learning (UDL), in contrast, is retained as a complementary pedagogical framework addressing learner variability through multiple means of engagement, representation, and action/expression.

Theoretical Synergies and Conflicts

Montessori's design for a perfect environment for all children stands for the efficient credit, (Rosati, 2021). The convergence shows how Montessori prepared the environment that fits the UDL goals. (Rosati, 2021). For example, the commitment of Montessori to the manageable furniture by children based on size and weight satisfies the UD fundamentals of decreased physical effort and size and space for Approach and Use, though decreasing frustration and functional barriers caused by adult-sized settings. (Rosati, 2021). The environment which is governed by the rule "everything in its place and a place for everything" fits the principle of UD. (Rosati, 2021).

In addition, the pedagogical alignment is strong: Montessori's multisensory, concrete, and self-correcting materials support the UDL principle of Multiple Means of Representation by engaging visual, tactile, and auditory sensory modalities simultaneously to introduce concepts (Rosati, 2021). The emphasis on free choice, repetition, and self-correction supports the UDL principle of Multiple

Means of Engagement, fostering persistence, self-regulation, and resilience (Rosati, 2021). A significant tension nevertheless exists between Montessori's open-plan layouts and UDL-informed requirements for clear environmental cues and sensory management. Montessori provides the open-plan continuous spatial layouts for promoting unconstrained motion and community interactions. (Hashimoto et al., 2025; Jojy & Prakash, 2025). Freedom of movement is guaranteed in this way (Rosati, 2021), but due to varying activity schedules in open environments, noise stress affects the concentration of specialized works (Meuser, 2019; Victoryana et al., 2024). On the other hand, there is a physical environment need for UDL to accommodate the needs of diverse sensory input and management (Bertling et al., n.d.). Architectural solutions are needed when these conflicts come to initiation to achieve polyvalence the capacity for a space to support highly structured, focused individual work alongside fluid group exploration—often through methods beyond fixed walls, such as flexible partitions (Pang et al., 2024).

The Critical Research Gap

It is indicated by the literature that the Montessori Method is very effective, which provides positive outcomes in cognitive and executive function (Lillard et al., 2025). Although the foundations of UD are theoretically aligned with Montessori's prepared environment (Rosati, 2021), a critical knowledge gap prevents systematic, high-fidelity integration. A critical lack of empirical research exists concerning UDL implementation in preschool and early years education across systematic reviews of European school settings (Ewe & Galvin, 2023).

In addition, research of UDL focuses on qualitative metrics like perception of engagement more than measuring objective learning outcomes or achievement (Ewe & Galvin, 2023).

Empirical validations miss regarding specific architectural elements such as the optimal geometry of flexible partitioning or the precise sensory management required for neurodiverse learners as indicated by the methodological gaps. Importantly, the data that connects variation in architectural implementation fidelity to student outcomes is not yet fully available to researchers that makes the procedure difficult to determine the level of fidelity required in the built environment (Lillard et al., 2025). This research proposes that the Universal Montessori Kindergarten Design Framework provides rigorous, measurable criteria that integrate Montessori pedagogical fidelity with UD/UDL architectural mandates, thereby bridging this critical gap.

METHODOLOGY

The development of the Universal Montessori Kindergarten Design Framework (UMKDF) followed a qualitative framework-development methodology designed to synthesize educational theory with evidence-based architectural knowledge. The study was based exclusively on secondary evidence and consisted of three stages: systematic literature review, secondary comparative analysis of established architectural case studies, and design framework synthesis. No primary data were collected from Montessori educators, architects, inclusive education specialists, children, or other users. Accordingly, the purpose of the present study was to develop and analytically examine the proposed framework rather than to provide empirical stakeholder validation. Figure 1 summarizes the progression from theoretical inputs to comparative analysis and framework synthesis.

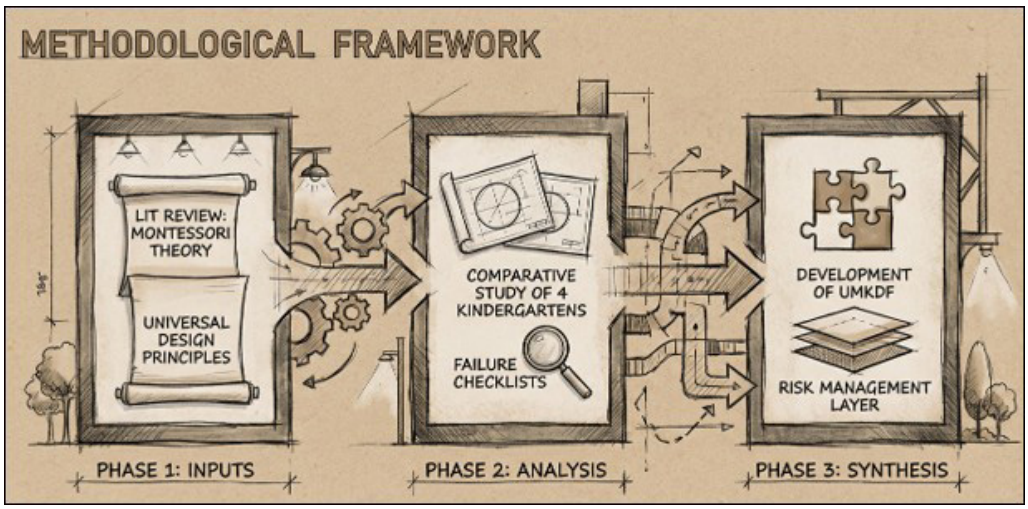

Figure 1. The methodological framework illustrating the progression from theoretical synthesis to the development of the UMKDF
Source: Produced by the authors with generative AI assistance; reviewed and edited by the authors.

Research Methodology

Systematic Literature Review

A comprehensive review of foundational pedagogy is included in the first stage which synthesizes the theories to extract the core principles that serve as the theoretical "inputs" for the UMKDF (Rosati, 2021). Three primary theoretical pillars are focused in this review. Firstly, the definitions of the Prepared Environment Autonomy, Sensorial Learning, and Child-Centred Scaling stand as the main principles of Montessori Pedagogy that are extracted. (Casha, 2015). These principles establish the pedagogical requirements for spatial function, such as the need for lightweight, movable furniture and unconstrained movement (Casha, 2015). Secondly, the architectural principles of Universal Design (UD) and the pedagogical framework of Universal Design for Learning (UDL) were analysed (Rosati, 2021). The architectural accessibility requirements were formalized against all seven Principles of Universal Design: Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use (Center for Universal Design, 1997). The principles of UDL documents a proactive approach to ensure equitable access and meaningful participation for diverse learners (Bertling et al., n.d.)

Secondary Comparative Analysis of Established Case Studies

In the second stage, four existing kindergarten case studies were examined to identify successful design patterns and practical failure scenarios: Fuji Kindergarten (Japan), My Montessori Garden Preschool (Vietnam), Ihsan Doğramacı Montessori Kindergarten (Turkey), and DPS Kindergarten (India) (Hashimoto et al., 2025; Pang et al., 2024; Khan & Ebrahimi, 2021; Jojy & Prakash, 2025). Circular, open-plan layouts, flexible partitions, and seamless indoor-outdoor continuity were included in successful patterns (Hashimoto et al., 2025; Pang et al., 2024). Importantly, the case-study source highlighted the importance of locating the kitchen and dining areas adjacent to one another as a functional planning consideration (Khan & Ebrahimi, 2021). This analysis yielded essential architectural data and a checklist of failure prevention requirements.

Framework Synthesis

The final stage contained synthesis of the theoretical principles was built in stage 1 with the pragmatic design lessons and failure checklists extracted in Stage 2. Mapping the main Montessori spatial needs (e.g., freedom of movement) was involved in this synthesis to corresponding UD principles (e.g., Equitable Use) to define specific architectural criteria (Rosati, 2021). The outcome of this phase is the Universal Montessori Kindergarten Design Framework (UMKDF), which

integrates pedagogical inputs, spatial transformation mechanisms, defined design outputs, and necessary risk-control layers to ensure both educational fidelity and universal accessibility (Casha, 2015; Bertling et al., n.d.).

Study Scope and Validation Boundary

The present study is limited to conceptual framework development based on secondary evidence. The literature synthesis and comparative case study analysis provide an analytical foundation for developing the UMKDF, but they do not constitute empirical validation by stakeholders or end users. Consequently, the framework's practical usability, stakeholder acceptability, and contextual adaptability remain to be empirically examined. Future studies should validate the UMKDF through semi-structured interviews or focus-group discussions with Montessori educators, architects specializing in child-centred environments, and inclusive education specialists, followed where possible by post-occupancy evaluation in operational kindergarten settings. Such future POE should incorporate measurable environmental, behavioural, safety, accessibility, and educational indicators to test whether greater fidelity to UMKDF principles is associated with improved real-world outcomes.

Retrospective Scoring Procedure and Operational Rubric

To reduce interpretive subjectivity, the retrospective scoring system was operationalised as an evidence-constrained ordinal rubric based on predefined and observable architectural indicators documented in the cited case-study sources. A score of 0 indicates documented non-compliance or a documented failure condition; a score of 1 indicates partial, mixed, indirect, or insufficiently documented compliance; and a score of 2 indicates clearly documented compliance supported by explicit architectural features or measured performance where such data are available. Criterion-specific rules were defined as follows. Spatial flexibility: 0 = predominantly fixed or cellular/ walled configuration with no documented adaptability; 1 = mixed fixed and flexible spatial configuration; 2 = predominantly open or modular configuration with documented movable elements, flexible zoning, or continuous circulation. Anthropometric responsiveness: 0 = no documented child-scaled adaptation; 1 = partial or selective child-scaling; 2 = consistent documented evidence of child-scaled furniture, fixtures, or access elements.

Acoustic risk control: 0 = documented noise-related problems without documented mitigation; 1 = partial or indirect control, or insufficiently documented acoustic performance; 2 = explicit evidence of an engineered acoustic-control strategy and/or measured acoustic performance consistent with recognized reverberation-time, speech-intelligibility, or sound-absorption criteria.

Sightline performance: 0 = documented obstruction of visual supervision; 1 = partial, mixed, or insufficiently documented sightline performance; 2 = explicit evidence of clear visual supervision through low or transparent partitions or an unobstructed layout. Absence of a reported problem was not treated as evidence of full compliance, and where evidence was incomplete or ambiguous, a score of 2 was not assigned. The rubric therefore standardizes the interpretation of secondary evidence but does not replace direct physical measurement or independent expert assessment.

The Universal Montessori Kindergarten Design Framework

The methodology described above produced the Universal Montessori Kindergarten Design Framework (UMKDF) as a systemic tool for translating integrated educational and accessibility principles into reproducible

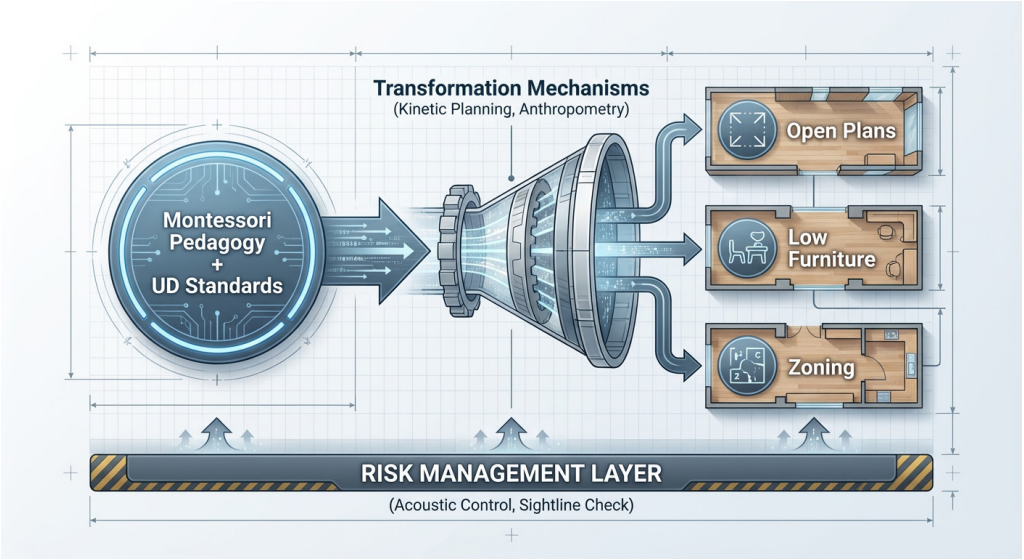

Figure 2. The Universal Montessori Kindergarten Design Framework (UMKDF) system architecture diagram. This visual schema details how abstract pedagogical and accessibility inputs are filtered through architectural transformation mechanisms to produce. Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

architectural design (Rosati, 2021). The UMKDF is structured into a logical, four stage process which guarantees that abstract theory is converted into concrete and evaluable design outputs in a systematic way. Figure 2 illustrates the systematic architecture of the UMKDF, demonstrating the flow from theoretical inputs through transformation mechanisms to verifiable outputs, all underpinned by a protective risk-control layer.

Inputs (Pedagogical & Accessibility)

This basic and important layer consist of the main integrated foundations which is taken from the systematic review. All the pedagogical inputs are the basic tenets of Montessori, emphasizing the Prepared Environment, Autonomy, and Sensorial Learning (Casha, 2015; Rosati, 2021). The architectural accessibility inputs are aligned with the seven Principles of Universal Design Equitable Use, Flexibility in Use, Simple and Intuitive Use, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use—while UDL provides the complementary pedagogical dimensions of engagement, representation, and action/expression (Center for Universal Design, 1997; Rosati, 2021). As an example, the Montessori need for lightweight, movable furniture aligns directly with the UD principle of Low Physical Effort, forming a single requirement for accessible, child-sized furnishings (Rosati, 2021). Similarly, the commitment of Montessori to multi-sensory materials supports the UDL principle of Multiple Means of Representation (Rosati, 2021; Utami & Ishartiwi, 2025).

Spatial Transformation Mechanisms

These strategies translate abstract theoretical inputs into concrete design actions, focusing on the way in which spaces are modified to support pedagogical goals and universal access (Casha, 2015). The main mechanisms include anthropometric detailing, which requires all fixed and movable elements to be dimensioned according to children's anthropometric measurements, thereby promoting independent use (Casha, 2015; Pang et al., 2024). The next mechanism is the implementation of Kinetic and Non-Linear Planning, preparing open-plan layouts and flexible partitions (e.g., low-height shelving) to define polyvalent zones and enhancing Freedom of Movement (Hashimoto et al., 2025; Pang et al., 2024). In addition, this phase contains Material and System Honesty that uses natural and authentic materials (wood, glass) and potentially exposing structural or operational systems (e.g., pipework) that are used to transform the building into a didactic, multi-sensory resource (Casha, 2015).

Design Outputs

This phase composes the tangible architectural results that are taken from the transformation mechanisms that provide measurable and verifiable metrics for construction and design review. The plans that are included in these outputs must illustrate open-plan, non-rigid layouts, often in circular or irregular forms (Hashimoto et al., 2025). The sections must indicate the Anthropometric Detailing which requires lowered window sills, and comply with minimum ceiling height requirements of at least 2.5 m (Casha, 2015; Meuser, 2019). The use of flexible partitioning and the inclusion of specialized areas and areas for quiet retreat and individual introspection are defined by the zoning outputs. (Li & Zhao, 2023; Casha, 2015). It must be ensured that the circulation patterns must be clear, continuous, and integrated with Motor Affordances (e.g., ramps, multi-level platforms) (Hashimoto et al., 2025; Carrasco, 2025). Finally, Furniture output requires elements that are lightweight, movable, and scaled (e.g., stool heights from 130 mm to 360 mm) (Casha, 2015; Meuser, 2019).

Risk-Control Layers

The last component of the UMKDF stands as a confirmation step, which consists of engineered measures to mitigate predictable failures identified in case studies (Khan & Ebrahimi, 2021). These controls ensure that the pursuit of open architecture does not compromise safety or pedagogical effectiveness. Acoustic Engineering Control is the core part of the main layers that mandate the proactive use of sound-absorbing materials used to reduce the risk of noise stress in open settings that affects concentration (Li & Zhao, 2023; Meuser, 2019). For design-stage verification, the acoustic-control layer should be checked against measurable reverberation-time, speech-intelligibility, and material-absorption criteria, as detailed in Risk Management Layer section and Table 3. Low-weight furniture and transparent construction are required for the sightline integrity check to ensure continuous supervision and prevent obstructed views (Jojy & Prakash, 2025). Operational risks are managed through the Facility Adjacency Check, which verifies that complementary areas (e.g., kitchen and dining) are located adjacent to each other, thereby avoiding workflow deficiencies (Khan & Ebrahimi, 2021). Finally, the Accessibility Surface Check prohibits uneven paving in outdoor areas, ensuring Equitable Use for all children (Casha, 2015).

CASE STUDY ANALYSIS

Study Analysis: Integrating Montessori and Universal Design in Kindergarten Architecture. This analysis examines Kindergarten case studies against the main requirements of Montessori pedagogy and Universal Design (UD) principles to systematically extract measurable design lessons and recognize critical failure patterns.

Moving from theory to practice, landmark case studies reveal successful design patterns and practical failures in the integration of Montessori and inclusive architecture. In successful models, the built environment is re-conceptualized as an active, multi-sensory "third teacher" (Carrasco, 2025).

Successful design patterns: Kinetic and non-linear planning are consistently indicated in Effective design, which is seen in Fuji Kindergarten's circular, open-plan layout and continuous roof playground that directly supports unconstrained motion and cognitive development (Hashimoto et al., 2025). Using low-weight, movable furniture and shelving as flexible separators were achieved by the removal of rigid, hierarchical boundaries that are used instead of walls that empowers autonomy and adaptable zoning (Pang et al., 2024; Jojy & Prakash, 2025). Furthermore, the commitment to seamless outdoor-indoor transition which was facilitated by large glass façades and gliding doors (Hashimoto et

al., 2025), evolves Sensorial Learning by providing continuous visual and physical connection to nature, which is extremely critical for stress reduction and exploration (Jojy & Prakash, 2025). Leveraging verticality is included in the next successful patterns by multi-level platforms (Carrasco, 2025) and utilizes natural and objective materials (e.g., wood, bamboo) to enrich the sensory experience (Two et al., 2023).

Practical challenges and failures: Practical implementation usually introduces vital challenges despite of philosophical alignment. Aural stress stands as a remarkable risk in open-plan or dynamic environments like Fuji Kindergarten, where high background noise levels can disrupt concentration (Meuser, 2019; Victoryana et al., 2024). In addition, custom designs like DPS Kindergarten, which are known by rigid structure and walled separations, limits the Freedom of Movement and create obstructed view that leads to supervision failures and restricted interaction (Jojy & Prakash, 2025). The analysis of Ihsan Doğramacı Montessori Kindergarten indicates that, although the school seeks to apply Montessori principles, deficiencies in the existing architecture and materials affect the quality of the educational environment. The source also reports insufficient use of indoor and outdoor spaces and emphasizes the importance of locating the dining room and kitchen side by side (Khan & Ebrahimi, 2021). In the present study, these reported deficiencies are interpreted as potential limitations related to the UD principle of Equitable Use (Center for Universal Design, 1997; Khan & Ebrahimi, 2021).

Part 2: Comparative Synthesis Matrix

To enable a structured and objective comparison, a comparative synthesis matrix is constructed based on the core evaluation criteria derived from the UMKDF framework. A scoring-based assessment selected case studies across key dimensions is presented in the table which includes spatial flexibility, anthropometric responsiveness, and risk management performance. Table 1 presents the Comparative synthesis matrix of the selected kindergarten case studies based on Montessori compliance, Universal Design compliance, Spatial flexibility, key strengths and major failure risks.

THE UNIVERSAL MONTESSORI KINDERGARTEN DESIGN FRAMEWORK (UMKDF)

The development of the Universal Montessori Kindergarten Design Framework (UMKDF) followed a wonderful qualitative research process designed to synthesize foundational educational theory with evidence-based architectural practice based on three-stages. This methodology provides a renewable design process which is essential to address the current research flaw concerning the systematic application of inclusive design foundations within early childhood education environments (Ewe & Galvin, 2023). The UMKDF is structured into four-stage process which ensures that abstract theory is systematically converted into concrete, evaluable design outputs.

Framework Inputs (Pedagogical & Accessibility)

The initial phase consisted of a Systematic Literature Review to establish the theoretical "inputs" for the UMKDF (Rosati, 2021). This included extracting the main spatial foundations of Montessori Pedagogy, which explains the Prepared Environment (Casha, 2015; Rosati, 2021), Autonomy and Independence (Casha, 2015; Hashimoto et al., 2025), Freedom of Movement (Rosati, 2021), and Child-Centered Scaling (Pang et al., 2024; Casha, 2015). Also, the framework formalized accessibility which is taken from Universal Design (UD) and Universal Design for Learning (UDL) that shows us to understand that the UD is directly inspired by Montessori's design philosophy (Rosati, 2021). The architectural

Feature	Fuji Kindergarten (Japan)	My Montessori Garden Preschool (Vietnam)	Ihsan Doğramacı Montessori Kindergarten (Turkey)	DPS Kindergarten (India)
Montessori Compliance	High (Oval form, autonomy, free movement) (Hashimoto et al., 2025)	High (Open-plan, child-scaled furniture, flexible zoning) (Pang et al., 2024)	Montessori model adopted; principles reportedly applied as far as possible, although architectural and material deficiencies remain (Khan & Ebrahimi, 2021)	Low (Rigid structure, walled separation restricts movement) (Jojy & Prakash, 2025)
UD Compliance	High (Scale, equitable access, visual transparency) (Hashimoto et al., 2025; Rosati, 2021)	High (Anthropometric scale, Low Physical Effort via movable furniture) (Pang et al., 2024)	Limited (Reported architectural and material deficiencies may constrain inclusive use; UD-specific compliance was not directly assessed) (Khan & Ebrahimi, 2021)	Low (Obstructed views, limited movement, rigidity) (Jojy & Prakash, 2025)
Spatial Flexibility	Very High (Open-plan, movable partitions, continuous roof play) (Hashimoto et al., 2025; Pang et al., 2024)	High (Open-plan with flexible separators) (Pang et al., 2024)	Insufficiently documented (underuse of indoor and outdoor spaces is reported, but spatial adaptability is not directly assessed) (Khan & Ebrahimi, 2021).	Low (Rigid structure, walled separations) (Jojy & Prakash, 2025)
Key Strength	Seamless indoor-outdoor flow via gliding doors and nature integration (Hashimoto et al., 2025)	Use of low-height, movable furniture as highly flexible separators (Pang et al., 2024)	Montessori principles are reportedly applied as far as possible; classroom materials are arranged within children's reach (Khan & Ebrahimi, 2021).	May mitigate general background noise better due to compartmentalization (Meuser, 2019)
Key Failure/ Risk	Potential for noise stress and disruption due to maximum openness (Victoryana et al., 2024)	Risk of noise stress due to open structure; lack of documented acoustic strategy (Meuser, 2019)	Insufficient use of indoor and outdoor spaces; inadequate interior facilities and materials; need for appropriate adjacency between kitchen and dining areas. (Khan & Ebrahimi, 2021)	Obstructed views leading to supervision failures; under-stimulation (Jojy & Prakash, 2025)

Note: Qualitative classifications represent the authors' analytical synthesis of the cited case-study evidence and are not ratings reported by the original sources.

Table 1. Comparative synthesis matrix of selected kindergarten case studies.
Source: authors' synthesis based on the cited literature.

accessibility inputs are structured against all seven Principles of Universal Design, while UDL contributes complementary pedagogical requirements related to multiple means of engagement, representation, and action/expression. The direct correspondence between these principles and the UMKDF architectural requirements is presented in Table 2. To broaden the inclusivity scope of the UMKDF, the accessibility inputs are organized into four user-need domains. First, physical and mobility need address barrier-free movement, reach, child-scaled access, and low physical effort. Second, sensory and perceptual need address acoustic comfort, multi-sensory information, environmental legibility, and the reduction of sensory overload. Third, cognitive and learning need address learner variability through flexible spatial configurations and multiple opportunities for engagement and representation. Fourth, emotional and self-regulatory needs address the availability of quiet retreat spaces, opportunities for focused individual activity, and controlled transitions between high- and

Table 2. Direct mapping of UMKDF inputs to the Seven Principles of Universal Design

Official Universal Design Principle	Corresponding UMKDF Input / Requirement	Architectural Translation within UMKDF
1. Equitable Use	Inclusive access; physical/mobility needs	Barrier-free circulation, accessible surfaces, equivalent access to indoor and outdoor learning areas
2. Flexibility in Use	Autonomy; freedom of movement; learner variability	Flexible zoning, movable furniture, adaptable activity areas, multiple spatial configurations
3. Simple and Intuitive Use	Prepared Environment; cognitive/ spatial legibility	Clear spatial organization, predictable zoning, consistent placement of learning materials, reduced unnecessary complexity
4. Perceptible Information	Sensorial Learning; sensory/ perceptual needs	Multi-sensory environmental cues, visual transparency, legible spatial information, complementary visual/tactile/auditory information
5. Tolerance for Error	Safety and risk-control requirements	Safe circulation, hazard reduction, supervision sightlines, protective elements, and risk-management checks
6. Low Physical Effort	Child-centered scaling; physical/ mobility needs	Lightweight movable furniture, lowered fixtures, accessible storage, reduced operating/reaching effort
7. Size and Space for Approach and Use	Anthropometric responsiveness; barrier-free access	Child-scaled dimensions, adequate approach and reach space, unobstructed circulation, accessible fixtures and activity zones

Source: Authors' synthesis based on Center for Universal Design (1997), Rosati (2021), Casha (2015), Bertling et al. (n.d.), and Pang et al. (2024).
Note: The seven UD principles provide the formal architectural accessibility structure of the UMKDF, while UDL functions as a complementary pedagogical framework addressing learner variability.

low-stimulation zones. These domains function as cross-cutting accessibility inputs within the UMKDF rather than as separate design systems.

Spatial Translation Mechanisms

The UMKDF integrates Spatial Transformation Mechanisms to change integrated theoretical inputs into rule-based, concrete design actions (Pang et al., 2024). Kinetic and Non-Linear Planning: The mix of Freedom of Movement (Montessori) and Flexibility in Use (UD) is meant into mandates for open-plan layouts used for non-rigid, continuous spatial configurations, often circular or irregular, to promote fluid exploration (Hashimoto et al., 2025; Jojy & Prakash, 2025). Zoning relies on flexible partitions, like low furniture or shelving, to define polyvalent activity zones while maintaining visual transparency (Pang et al., 2024).
Figure 3, illustrates the spatial shift from a rigid/ static classroom layout to the proposed UMKDF kinetic/ polyvalent plan, where flexible zoning, movable furniture and open circulation support freedom of movement and adaptive learning.

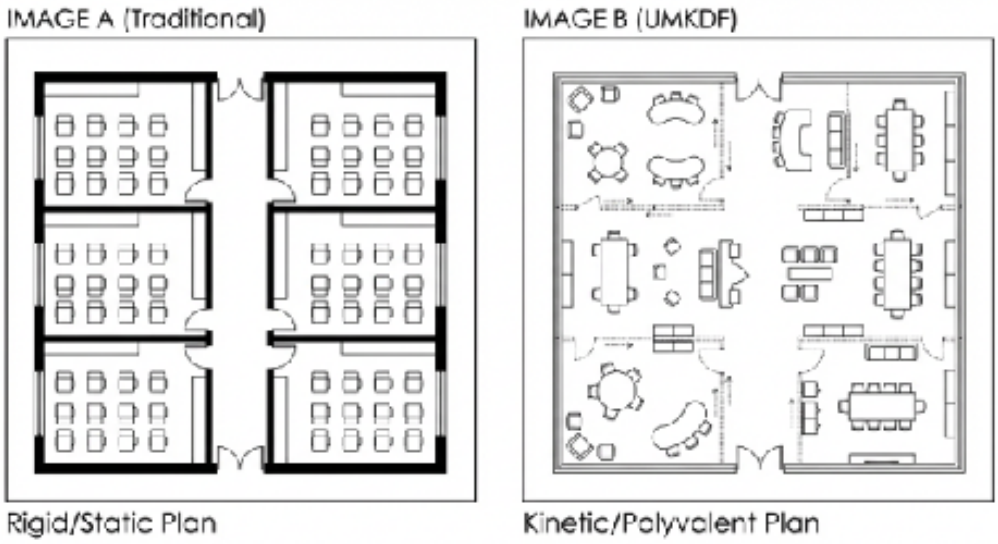

Figure 3. Comparative spatial analysis schema. (Left) A traditional 'Rigid/Static Plan' characterized by thick-walled cellular classrooms and fixed furniture, limiting movement and flexibility. (Right) The proposed UMKDF 'Kinetic/Polyvalent Plan' utilizing flexible zoning, movable furniture and continious ciculation.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

Anthropometric Detailing: The input for Child-Centered Scaling (Montessori) and Low Physical Effort (UD) needs all accurate elements such as sinks, and window sills that should be anthropometrically lowered to the child's size, which empowers self –reliance and unassisted function (Casha, 2015). It's important to consider that all the materials and staffs must be lightweight and easy for children to handle independently. (Rosati, 2021; Pang et al., 2024). Material and System Honesty: Sensorial Learning (Montessori) and Perceptible Information (UD) prioritize natural, objective, and non-toxic materials (wood, bamboo, glass) to enrich the multisensory experience (Two et al., 2023). This mechanism further mandates that structural or operational systems (e.g., pipework) be exposed to function as didactic sensory resources (Casha, 2015).

Design Control System (Design Outputs)

The Design Control System describes the quantifiable architectural outputs resulting from the translation mechanisms, establishing verifiable metrics for the final design and construction.

Plans and Zoning: Open-plan environments must be specified in the design outputs which integrate functional activity rooms required for scientific exploration alongside larger activity areas. (Li & Zhao, 2023). Zoning implies flexible partitioning to maintain continuity while integrating areas for quiet retreat and individual introspection (Casha, 2015).

Sections and Scale: The drawings from each section should verify Anthropometric Detailing across all fixtures (Casha, 2015) and confirm compliance with minimum ceiling heights of at least 2.5 m (Meuser, 2019). Some elements like play stools are needed for the furniture to conform to defined anthropometric ranges, starting at 130 mm (Meuser, 2019). Figure 4 shows the precise application of these anthropometric standards illustrating the relationship between the child's stature, reach radius and furniture height.

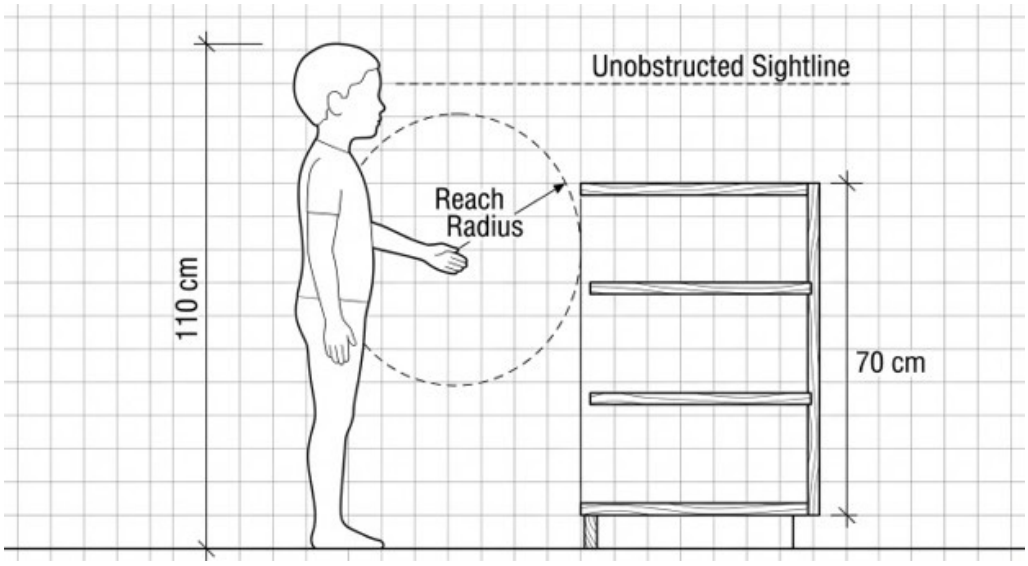

Figure 4. Anthropometric section detailing the 'Child-Centered Scaling' design output. The diagram illustrates a 5-year-old child (110 cm stature) interacting with a low-height shelving unit (70 cm). The 'Reach Radius' affirms unassisted access to materials. It validates the anthropometric calibration of spatial elements and reinforces independence, autonomy, and self-directed activity as core principles of the Montessori learning environment.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

Circulation: Circulation output mandates clear, continuous, and unobstructed paths to maximize Freedom of Movement (Rosati, 2021). Pathways must be multifunctional and should integrate motor affordances like ramps and multi-level platforms to stimulate physical exploration (Hashimoto et al., 2025; Carrasco, 2025). A seamless transition is mandated using large gliding doors or glass facades to ensure visual connectivity with nature (Hashimoto et al., 2025; Jojy & Prakash, 2025).

Risk Management Layer

The last and final component of the UMKDF works as a certification and safety system that implements engineered measures to mitigate predictable failures thus ensuring UD compliance and functional adequacy.

Mitigation of Sensory Overload (Acoustic Stress): The acoustic-control layer of the UMKDF should be specified through measurable performance criteria rather than through generic recommendations for "sound-absorbing materials." As an external design benchmark, nursery school rooms should target a mid-frequency reverberation time (Tmf) of ≤ 0.6 s, while open-plan teaching areas should target Tmf ≤ 0.5 s (Department for Education, 2015). For open-plan learning environments, speech intelligibility should also be considered; Building Bulletin 93 specifies a Speech Transmission Index (STI) of ≥ 0.61 within an instructional group and ≤ 0.30 between simultaneously operating groups (Department for Education, 2015). Architecturally, acoustic control should prioritize a continuous sound-absorbing ceiling, supplemented where necessary by absorptive wall panels, ceiling baffles, or other tested absorbers. As a practical specification benchmark, ceiling and wall absorbers with a Noise Reduction Coefficient (NRC) of approximately 0.70 or higher can provide high sound absorption, while rooms with ceilings above approximately 3 m may require additional wall treatment to achieve the required reverberation-time target (Alberta Infrastructure, 2026). Low-height furniture partitions used to preserve Montessori flexibility should incorporate tested sound-absorbing surfaces where they are intended to provide acoustic separation, while remaining low enough to preserve adult supervision sightlines. No fixed room-volume ratio is prescribed in the UMKDF because the required amount and placement of absorption depend on room geometry, occupancy, surface finishes, and activity patterns. Final acoustic performance should therefore be verified through room-acoustic modelling and, where possible, post-occupancy measurement rather than inferred from the presence of acoustic materials alone. Table 3 summarizes the acoustic performance benchmarks and corresponding architectural responses proposed for UMKDF learning spaces.

Mitigation of Sensory, Perceptual, and Cognitive Exclusion: The UMKDF extends risk management beyond physical accessibility by considering children who may experience sensory overload, perceptual difficulty, or different cognitive

Table 3. Acoustic performance benchmarks and architectural responses for UMKDF learning spaces

Acoustic parameter	Proposed UMKDF design benchmark	Architectural response
Nursery learning-space reverberation time	Tmf ≤ 0.6 s	Sound-absorbing ceiling; wall absorption where required
Open-plan teaching-area reverberation time	Tmf ≤ 0.5 s	Increased ceiling/wall absorption and acoustic zoning
Speech intelligibility within instructional group	STI ≥ 0.61	Control background noise and reverberation; orient activity zones appropriately
Speech transmission between simultaneous groups	STI ≤ 0.30	Spatial separation, absorptive screens/partitions, and activity zoning
Ceiling/wall sound absorption	NRC ≈ 0.70 or higher as a practical design benchmark	Acoustic ceiling panels, absorptive wall panels, baffles, or equivalent tested systems
High ceilings / large reflective volumes	Additional acoustic treatment required	Add wall absorbers and verify performance through acoustic modelling
Flexible Montessori partitions	Tested absorptive surfaces where acoustic separation is intended	Low-height sound-absorbing furniture partitions preserving supervision sightlines

Source: Authors' synthesis based on Department for Education (2015) and Alberta Infrastructure (2026).
Note: The values are presented as design benchmarks rather than universal regulatory requirements; applicable national/local acoustic standards should govern final project specifications.

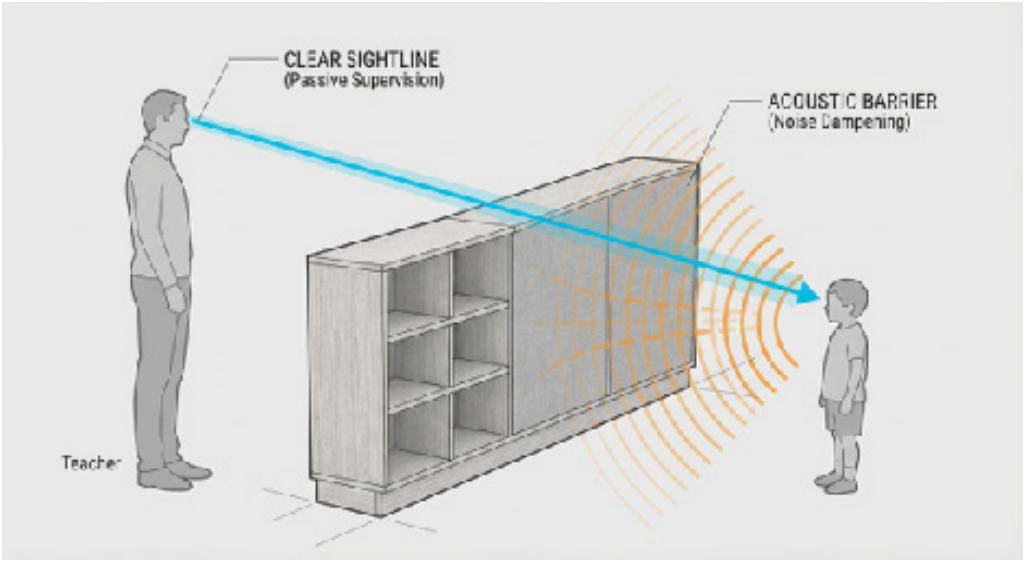

Figure 5. The Risk Management Layer mechanism. This conceptual diagram demonstrates how low-height, dual-sided furniture functions as an 'Acoustic Barrier' to mitigate noise stress between zones and as a 'Sightline Preservation Tool' that enables continuous passive supervision by teachers, thereby integrating sensory regulation with visual control in open-plan environments.

Source: Produced by the authors with generative AI assistance; Reviewed and edited by the authors.

and learning needs. Inclusive spatial responses include the provision of low-stimulation retreat areas, clear and consistent spatial organization, multi-sensory environmental cues, flexible activity zones, and multiple forms of engagement with learning materials. These measures are intended to reduce sensory and cognitive barriers while preserving the Montessori principles of autonomy, choice, and self-directed activity (Bertling et al., n.d.; Rosati, 2021; Casha, 2015). Mitigation of Physical Safety and Supervision Failure: All the fixtures and furniture are low-height which is ensured by the Sightline Integrity Check to maintain continuous adult supervision and prevent obstructed views (Casha, 2015; Jojy & Prakash, 2025). Furthermore, layered safety measures (e.g., nets, railings) must be integrated when utilizing structures for risk exploration (Casha, 2015). A conceptual diagram illustrating how low-height furniture simultaneously functions as an acoustic dampener and a tool for maintaining clear sightlines for passive supervision is shown in Figure 5 below.

Mitigation of Accessibility Failure: The Accessibility Surface Check don't allow the use of hazardous or uneven surfaces (e.g., uneven concrete paving) in outdoor areas, ensuring barrier-free movement and inclusive access (Casha, 2015). Physical accessibility is also fixed by providing varied ramps and chutes for children whether they are standing or seated (Bertling et al., n.d.).

Mitigation of Pedagogical/Operational Mismatch: The Facility Adjacency Check checks that related functional zones (e.g., kitchen and dining) are next to each other to prevent workflow deficiencies that undermine the Prepared Environment (Khan & Ebrahimi, 2021). This layer also requires the strategic integration of quiet spaces, such as nooks and alcoves for kids to have alone time, to balance the high stimulation of the communal, open environment (Casha, 2015).

RESULTS AND DISCUSSION
Analytical Findings (Results)
Analytical Assessment: Synergy and Compatibility

The analytical process verified a powerful theoretical alignment between main Montessori Pedagogy and Universal Design (UD) principles that validates the UMKDF's premise that the two systems are highly compatible. The compatibility Matrix has shown, the concept of UD, that concentrates on designing for all needs, inspired by Montessori's original philosophy for creating an environment

that fulfils the requirements of all children. This synergy results in areas of strong compatibility where Montessori architecture inherently fulfils UD objectives.
The high degree of order required by the Prepared Environment aligns with the UD principle of Simple and Intuitive Use, which results in the development of internal psychological order in children and aids spatial understanding. The architectural mandate for accessible furniture aligns with the UD principles of Low Physical Effort and Size and Space for Approach and Use, which help remove the physical obstacles associated with adult-scaled settings. Based on the pedagogy, the multi-sensory and self-correcting materials attach directly to the UDL principles of Multiple Means of Representation and Action and Expression. Compatibility is necessary in areas such as technology integration, in which the UMKDF should adapt the approaches of UDL while respecting Montessori's fundamental preference for concrete and tangible materials.

The direct mapping presented in Table 2 demonstrates that the UMKDF is not limited to selected accessibility concepts but is terminologically aligned with all seven Principles of Universal Design. Equitable Use and Size and Space for Approach and Use are primarily reflected in barrier-free circulation and anthropometric detailing; Flexibility in Use is reflected in adaptable zoning and movable furnishings; Simple and Intuitive Use and Perceptible Information are reflected in spatial legibility and multi-sensory environmental cues; Tolerance for Error is operationalized through the Risk Management Layer; and Low Physical Effort is supported through child-scaled, lightweight, and independently usable elements.

Retrospective Analytical Application: UMKDF Scoring Matrix

Using the predefined operational rubric described in Section 3.1.5, the selected case studies were retrospectively classified across four criteria: spatial flexibility, anthropometric responsiveness, acoustic risk control, and sightline performance. The 0–2 scores were assigned from explicitly documented secondary evidence rather than from direct physical measurements or independent expert ratings. Accordingly, the matrix provides a structured comparative interpretation of the available evidence and should not be interpreted as empirical quantitative validation. Table 4 presents the resulting evidence-based classifications.

Table 4. Comparative Retrospective Scoring of Case Studies using UMKDF Criteria. Source: Authors' synthesis based on the cited literature.

Assessment Criteria (UMKDF Layers)	Fuji Kindergarten (Japan)	My Montessori Garden (Vietnam)	Ihsan Doğramacı Montessori Kindergarten (Turkey)	DPS Kindergarten (India)
1. Spatial Inputs (Flexibility)	2 (Highly Flexible)	2 (Modular)	1 (Insufficiently documented)	0 (Rigid/Walled)
2. Anthropometry (Scale)	2 (Child-Scaled)	2 (Child-Scaled)	1 (Partial child-scaling)	1 (Standard)
3. Risk Layer: Acoustics	0 (Fail - Noise Stress)	1 (Insufficiently documented)	1 (Calm classroom atmosphere reported; no measured acoustic performance)	1 (Indirect control; no measured acoustic data)
4. Risk Layer: Sightlines	1 (Obstructed by crowds)	2 (Clear)	1 (Insufficiently documented)	0 (Blocked by walls)

Note: Scoring scale: 0 = documented non-compliance/failure; 1 = partial, mixed, indirect, or insufficiently documented compliance; 2 = clearly documented high compliance. Scores were assigned according to the operational rubric defined in Retrospective Scoring Procedure and Operational Rubric section and represent ordinal classifications of secondary evidence rather than direct physical measurements or independent expert ratings.
For Ihsan Doğramacı Montessori Kindergarten, scores of 1 indicate partial or insufficiently documented evidence rather than confirmed non-compliance. The spatial-flexibility and sightline scores reflect insufficient documentation of spatial adaptability and visual-supervision performance. The anthropometric score reflects evidence that classroom materials are arranged within children's reach, although comprehensive child-scaled dimensions are not reported. The acoustic score reflects a descriptive account of a calm and quiet classroom atmosphere, without measured acoustic performance or a documented engineered acoustic-control strategy (Khan & Ebrahimi, 2021).

The retrospective application reveals criterion-specific performance profiles rather than a single overall ranking. Fuji Kindergarten demonstrates strong spatial flexibility and child-scaled design but also presents documented acoustic risk. DPS Kindergarten demonstrates limited spatial flexibility and obstructed sightlines, while its compartmentalized configuration may provide indirect acoustic separation without measured acoustic-performance evidence. My Montessori Garden demonstrates strong spatial flexibility and anthropometric responsiveness, although explicit acoustic-performance data remain insufficiently documented. Ihsan Doğramacı Montessori Kindergarten shows partial evidence of child-reachable materials and a calm classroom atmosphere; however, the available source provides insufficient documentation of spatial adaptability, measured acoustic performance, and sightline effectiveness.

These findings illustrate how the operational rubric can identify strengths, limitations, and evidence gaps across cases without treating the ordinal classifications as direct quantitative measurements.

Identified Conflicts and Research Gaps

The study of contradictions and restrictions has identified main divergence that needed systemic mitigation in the framework structure. The initial spatial contrast exists between the Montessori requirement for maximizing Freedom of Movement through open-plan layouts and the UDL need for different sensory management. The study of case issues verified that open designs like the Fuji Kindergarten holds a critical risk of noise stress because of high noise levels that are created by varying activities schedules, which disrupts the required focus for the individual work.

The tensions of the accessibility often raised from insufficient architectural execution, even in Montessori environments. Some of the failures like the irregular placement of the kitchen and the dining room created workflow flaws. In addition, design rigidities was seen in custom settings and patterns that are featured by walled separations, which led to obstructed views, resulting in useless supervision and weak connectivity to nature. The need to mandate clear and specialized functional areas like scientific discovery rooms with a flexible and non-hierarchical layout demonstrates a persistent spatial obstacle that decrees the framework's reliance on flexible partitioning.

Lastly, the analysis identified critical flaws that the UMKDF targets to fill. The most critical result of the study, taken from the Limitations Analysis, is the lack of practical research that is concerned UDL amplifications in preschool period. The existing research indicates qualitative methods that concentrates on students' and tutors' view of engagement more than thinking about the objective learning impacts or building a practical link between variations in architectural implementations fidelity and efficiency plus the quantifiable achievements of the students.

Discussion, Interpretation, and Implications
Educational and Architectural Impact

The solutions of the UMKDF integrated design is translated as mechanisms, used to formalize the architectural practice to idealize the educational results. The mandate for using child-sized, lightweight, and movable furniture reinforces the Montessori goal of nurturing autonomy and independence (Casha, 2015; Rosati, 2021). Self-activity flourishes automatically when the unassisted moving of the staffs are done by the children themselves and it decreases the reliance of them on others such as employees or tutors. (Casha, 2015; Lillard et al., 2025). According to the regulation of sensory, the framework's inclusion of Acoustic

Engineering Control mitigates the spatial contrasts which were recognized in the open-plan model. (Victoryana et al., 2024). This effective measure stands against noise stress and empowers focus that makes sure that the Prepared Environment remains conducive to highly focused individual work (Li & Zhao, 2023). According to the architecture, the framework empowers an essential shift away from rigid compartmentalized classrooms toward structures that function as an active, multi-sensory "third teacher" (Carrasco, 2025). The empowerment of clear construction and low furniture (Sightline Integrity Check) ensures continuous sight lines (Jojy & Prakash, 2025), that allows non-intrusive observation and supervision essential for effective pedagogical guidance (Hashimoto et al., 2025). In addition, designing dynamic circulation systems like integrating ramps and diverse levels, influences educational performance by stimulating motor skills and maximizing exploration, which is crucial for cognitive development (Casha, 2015; Hashimoto et al., 2025).

At the architectural scale, the UMKDF operates across three interrelated levels. At the building scale, it addresses barrier-free access, indoor–outdoor continuity, and the overall relationship between learning environments and circulation systems. At the spatial-planning scale, it organizes zoning, adjacency, movement routes, sightlines, high- and low-stimulation areas, and flexible learning territories. At the architectural-detail scale, it specifies anthropometric fixtures, movable partitions, material properties, acoustic treatments, and accessible furniture. This multi-scalar structure extends the framework beyond interior furnishing decisions and positions the UMKDF as an integrated architectural design framework for inclusive kindergarten environments.

Policy Relevance

The UMKDF amounts some criteria with fully relevant criteria that is evidence-based for educational and disability inclusion policy. The framework underpins the architectural design required to sustain the cost-effective structure of public Montessori schools (Lillard et al., 2025). The model supports the practice of internationally higher child-to-teacher ratios by accommodating the high-fidelity design standards that leverages peer tutoring and the self-regulating environment. (Lillard et al., 2025). The capacity of architecture contributes directly to the model being which is estimated to 13,127$ less for a child over three years compared to traditional programs. (Lillard et al., 2025).

The UMKDF ensures UD to set the generalized principles into verifiable infrastructure mandates for inclusion policies. This requires Anthropometric Detailing (e.g., lowering sinks and handrails to child height) to promote unassisted function (Casha, 2015), and setting standards for Equitable Use, such as forbidding dangerous surfaces like uneven concrete paving (Casha, 2015). This framework is used to minimize the requirements for later expensive retrofitting by illustrating that the environment be set to create equitable access from outset (Bertling et al., n.d.), which supports systemic change across early childhood education infrastructure. (Ewe & Galvin, 2023). The framework also codifies spatial minimums, which requires a minimum of 10 square meters of outdoor space for each child to support motor coordination and natural engagement (Khan & Ebrahimi, 2021).

Limitations and Future Research

A principal methodological limitation of this study is the absence of primary empirical data. The UMKDF was developed through systematic literature synthesis and secondary comparative case study analysis rather than through direct engagement with Montessori educators, architects, inclusive education

specialists, children, or other end users. Consequently, the present findings establish a theoretical and analytical foundation for the framework but cannot demonstrate its stakeholder acceptability, practical usability, or effectiveness in real-world educational settings. These aspects require independent empirical validation in subsequent research.

Although the revised UMKDF explicitly maps its architectural inputs to all seven Principles of Universal Design, the Montessori-specific operationalization and relative importance of these principles are derived from secondary evidence rather than empirical stakeholder validation. Their contextual applicability and performance thresholds therefore require further empirical testing.

A further limitation concerns the retrospective scoring procedure. The classifications were performed by the authors using predefined operational criteria and documented secondary evidence rather than by multiple independent assessors. Although the operational rubric was introduced to reduce interpretive discretion, inter-rater reliability was not evaluated in the present study. Future empirical validation should therefore apply the rubric through multiple independent assessors and report inter-rater agreement, alongside direct environmental, spatial, and behavioural measurements.

Future research should adopt a sequential empirical validation strategy. First, semi-structured interviews and focus-group discussions with Montessori educators, architects, and inclusive education specialists should assess the clarity, relevance, feasibility, and contextual adaptability of the UMKDF. Second, the framework should be implemented or retrospectively evaluated in operational kindergarten settings through Post-Occupancy Evaluation (POE). Such evaluation should combine spatial and environmental measurements with behavioural and educational indicators. Quantitative measures may include A-weighted noise levels [dB(A)], duration of on-task attention, observed circulation conflicts, recorded accident or minor-injury incidents, accessibility barriers, and observable frustration events. Where ethically approved and methodologically appropriate, age-appropriate learning or cognitive measures may also be examined. Longitudinal follow-up could further determine whether any observed benefits persist over time. Together, these data would enable future studies to test whether greater architectural fidelity to UMKDF principles is associated with improved accessibility, safety, concentration, user experience, and educational outcomes.

Inconsistencies of specific non-academic outcomes such as the observed instance where some Montessori students showed slightly less persistence on a difficult, unvalidated puzzle task, despite the method's philosophical alignment with mastery and determination are also seek by the researchers to resolve the issue, (Lillard et al., 2025). To sum up, the studies must concentrate on creating systemic techniques to flourish wayfinding abilities through spatial design which is a current gap in architectural documentation (Jojy & Prakash, 2025).

CONCLUSION

The research has identified an important architectural and pedagogical gap between the distinctive spatial requirements of Montessori education and the contemporary mandate for comprehensive inclusion guided by Universal Design (UD) and Universal Design for Learning (UDL). The gap also reflects the absence of a systematic methodology for translating the theoretical compatibility between Montessori pedagogy and the principles of Universal Design (UD) and Universal Design for Learning (UDL) into measurable, failure-resistant architectural criteria.

The UMKDF was developed to address this gap. The UMKDF represents a novel conceptual and scientific contribution by providing a structured, reproducible framework for designing inclusive early childhood environments.

The UMKDF's architectural-operational structure follows a sequence: integrating foundational principles (Inputs), translating them through rule-based spatial strategies (Transformation Mechanisms, such as Kinetic and Non-Linear Planning), and verifying compliance via a Design Control System (e.g., Anthropometric Detailing).

The framework also incorporates risk-management layers (e.g., Acoustic Engineering Control, Sightline Integrity Check) that are designed to mitigate foreseeable failure scenarios and help ensure that the environment supports, rather than compromises, pedagogical goals (e.g., reducing noise-related stress in open plans). The UMKDF is designed to support equitable access to the educational benefits of Montessori by addressing physical and sensory barriers. In this framework, inclusivity extends beyond physical accessibility to encompass mobility, sensory/perceptual, cognitive/learning, and emotional/self-regulatory needs, thereby providing a broader interpretation of Universal Design within Montessori kindergarten environments.
At its current stage, the UMKDF should be regarded as a theoretically and analytically derived design framework rather than an empirically validated building standard. Therefore, broad policy adoption should follow, rather than precede, empirical testing. Future research should first examine the framework through evaluation by experts and relevant stakeholders and pilot application in operational kindergarten settings. Subsequent post-occupancy evaluation (POE) should combine environmental measurements, behavioural observations, safety and accessibility indicators, and appropriate educational measures to determine whether greater fidelity to UMKDF principles is associated with improvements in accessibility, safety, concentration, user experience, and learning outcomes. Evidence generated through such studies can then inform further refinement of the framework and its potential translation into architectural design guidance or policy.

Conflict of Interest

No conflict of interest was declared by the authors.

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Ethics Committee Approval

Ethics Committee approval was not required for this article.

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