architecture

Systematic Review

From Sensory Design to Regulatory Architecture: A Systematic Review of Inclusive Early Childhood Learning Environments for ASD, ADHD, and Down Syndrome

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Abstract

This study presents a systematic review and an integrative interpretive synthesis of the architectural literature addressing sensory–interactive design strategies in early childhood learning environments that support children with Autism Spectrum Disorder (ASD), Down Syndrome (DS), and Attention Deficit Hyperactivity Disorder (ADHD). Following a systematic review conducted in accordance with PRISMA 2020 guidelines, twenty-nine peer-reviewed studies were analyzed to examine how environmental design variables may influence sensory load, cognitive processing, emotional stability, and behavioral engagement across neurodevelopmental profiles. Rather than remaining within conventional descriptive approaches, architectural variables—including lighting, color, acoustics, materials, spatial configuration, and environmental controllability—are reconceptualized as regulatory dimensions shaping child–environment interactions. The synthesis suggests that identical environmental variables may elicit divergent, and at times conflicting, sensory–emotional and behavioral responses among children with ASD, DS, and ADHD, highlighting the limitations of standardized design solutions. Accordingly, the study proposes the Sensory–Interactive Architecture Framework (SIAF), an analytical framework that links neurodevelopmental response patterns with sensory–emotional regulation mechanisms and environmental design variables as regulatory dimensions. The findings indicate that effective inclusive design does not rely on generalized sensory interventions but rather on the deliberate regulation of sensory variability through more legible, graded, and controllable spatial systems, thereby promoting learning engagement, emotional stability, and adaptive behavior in neurodiverse children.

Keywords: sensory–interactive architectural design; early childhood learning environments; inclusive educational architecture; Autism Spectrum Disorder (ASD); Attention Deficit Hyperactivity Disorder (ADHD); Down Syndrome (DS)

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1. Introduction

Early childhood (ages 3–8) represents a critical developmental stage during which the neural, cognitive, and emotional foundations associated with attention, self-regulation, social interaction, and sensory response patterns are formed. Developmental neuroscience research indicates that this period corresponds to what are known as sensitive periods, during which the brain exhibits heightened plasticity and increased susceptibility to supportive or disruptive environmental characteristics, with direct implications for subsequent learning trajectories and behavioral outcomes. Within this context, the architectural and educational literature consistently emphasizes that the built environment during early childhood does not function as a neutral backdrop; rather, it is directly associated with the quality of educational experiences, emotional responses, and behavioral regulation, particularly among children with differences in sensory and cognitive processing patterns [1–6]. This highlights the need to examine how environmental design variables shape learning environments, particularly in light of evidence linking physical and sensory environmental conditions to children's attention, emotional responses, and developmental outcomes, especially among those with sensory and cognitive differences [3,5]. However, the architectural literature remains fragmented, with most studies focusing on ASD and limited integrative reviews examining ASD, DS, and ADHD together through a unified analytical framework.

Studies focusing on early childhood learning environments demonstrate that children exhibit heightened sensitivity to physical environmental characteristics, such as lighting intensity, noise levels, color schemes, and spatial organization. Inadequate regulation of these variables may lead to increased distractibility, reduced concentration, and the emergence of withdrawal or impulsive behaviors, even in the absence of direct educational or therapeutic interventions [7,8]. Furthermore, specialized reviews indicate that unbalanced lighting conditions and inappropriate color selections may exacerbate sensory overstimulation and cognitive load, particularly among children with Autism Spectrum Disorder, thereby underscoring the critical role of architectural design in shaping educational experiences during this sensitive developmental stage [9].

Within this framework, the literature has increasingly focused on groups of children with atypical neurodevelopmental and sensory processing profiles. Among these, Autism Spectrum Disorder (ASD), Attention Deficit Hyperactivity Disorder (ADHD), and Down Syndrome (DS) are frequently examined due to their distinct and well-documented sensory–cognitive characteristics. While other neurodevelopmental conditions exist, these three groups present contrasting patterns of sensory responsiveness, attention regulation, and spatial interaction, making them particularly relevant for comparative architectural analysis, especially given their well-documented sensory–cognitive variability and the growing attention to their environmental and educational implications within the literature, particularly in relation to school design and built environment needs [10–13]. Evidence indicates that children with ADHD experience pronounced differences in sensory and attentional processing, which are associated with heightened sensitivity to visual and auditory stimuli within educational settings [10,14]. In contrast, studies have shown that children with DS exhibit distinct sensory–cognitive processing patterns that may influence spatial perception, motor interaction, and responsiveness to highly stimulating environments [11,15]. Overall, existing studies suggest that built environment elements—including lighting, acoustics, color, spatial organization, and stimulus density—play a significant role in shaping cognitive, behavioral, and emotional responses among these groups, with considerable variability depending on both the condition and individual differences among children [12,16,17].

Building on these premises, contemporary architectural discourse has evolved from viewing the educational environment as a neutral backdrop for activities to recognizing it as an active regulatory factor that may influence attention, emotional regulation, social interaction, and spatial predictability within learning environments. Recent architectural studies have reinforced this shift, indicating that sensory–interactive architectural design has emerged as a key direction in early childhood architecture, given its potential to reduce sensory load, enhance spatial orientation, and support autonomy and self-regulation among children with neurodevelopmental and sensory differences [13,18–27].

Despite this theoretical and applied progress, a critical review of the literature reveals substantial research gaps, most notably the predominance of studies focusing on ASD, contrasted with the limited number of architectural studies addressing DS and ADHD, particularly within early childhood contexts. Moreover, there remains a clear absence of reviews that integrate all three neurodevelopmental conditions within a unified analytical framework that enables systematic comparison of their sensory and spatial requirements. In addition, the majority of architectural reviews remain confined to generalized design recommendations or isolated design elements, without advancing analytical frameworks or design matrices that can be translated into evidence-based decision-support tools.

Building on these identified gaps, this study aims to provide an integrative systematic review of the architectural literature related to sensory-informed design for early childhood learning environments that support children with ASD, DS, and ADHD, from an architectural perspective that emphasizes the interactions among spatial configuration, sensory regulation, and behavioral and emotional responses. It further seeks to identify shared and differentiated design strategies across these groups and to apply theoretical concepts such as sensory zoning, spatial sequencing, and transition and escape spaces to classrooms, corridors, outdoor yards, and therapeutic spaces.

Accordingly, the study proceeds from a central research question: how has the prior architectural literature evaluated sensory-informed design in early childhood learning environments that support these three neurodevelopmental groups, particularly regarding the interaction among spatial characteristics, sensory regulation, and behavioral and emotional responses? From this central inquiry, the following sub-questions are derived: Which sensory and spatial attributes are most frequently addressed in the literature for each group individually? To what extent do sensory-informed design strategies converge or diverge across children with ASD, DS, and ADHD? How have previous studies have examined the role of transition spaces, escape spaces, and spatial sequencing in reducing sensory load and facilitating transitions between learning activities? Which design principles or frameworks can be distilled from the literature to translate theoretical concepts into applicable design solutions within educational environments without generating institutionalized or restrictive spatial character?

The primary contribution of this research lies in the development of an architectural analytical framework and comparative design matrices that link built environment characteristics with children's cognitive, behavioral, and emotional responses. This contribution is intended to support evidence-based design decision-making in inclusive educational architecture and to provide an analytical perspective on how architectural design can function as a regulatory system, rather than presenting it as a definitive operational model.

2. Methodology

This study adopts a Systematic Literature Review (SLR) methodology to analyze and evaluate architectural research related to sensory–interactive architectural design for early childhood learning environments that support children with ASD, DS, and ADHD. The SLR approach was selected as it enables the structured synthesis of dispersed architectural evidence, reduces selection bias, and facilitates the identification of consistent and interpretable patterns. The review was conducted in accordance with the PRISMA 2020 guidelines, ensuring methodological transparency, traceability, and replicability of research procedures and findings [28,29]. A systematic review is defined as a structured process for identifying relevant studies, critically appraising their quality, and synthesizing their findings within a transparent analytical framework that enhances the reliability of conclusions and reduces bias [30].

Data Sources and Search Strategy: The literature search was conducted across multiple multidisciplinary academic databases widely used in architectural research and built environment studies, including Google Scholar, Scopus, and Web of Science, as well as other relevant sources, due to their broad coverage of peer-reviewed research in architecture, educational design, and environmental studies. The review was limited to publications from the past decade (2016–2025) to ensure the currency of evidence and alignment with recent developments in sensory-informed design for early childhood learning environments. While this temporal inclusion criterion (2016–2025) was applied strictly to the empirical studies included in the systematic review and analytical synthesis, selected seminal references predating this range (e.g., [2,4,21]) were incorporated to establish the theoretical and conceptual foundations of the study and were not included in the analytical synthesis.

The search strategy relied on compound search strings employing Boolean operators (AND/OR) and truncation symbols (*), including the following:

- "Sensory–interactive architectural design" AND "Early childhood learning environments" AND "Inclusive educational architecture" AND ("Autism" OR "Down Syndrome" OR "ADHD")
- "Sensory design" AND "Interactive architecture" AND "Early childhood learning environments" AND ("Autism" OR "Down Syndrome" OR "ADHD")

Search strings were adapted to the requirements of each database while maintaining conceptual consistency.

Study Selection and Screening: The initial search process yielded a total of 3047 records, including 2970 records from Google Scholar, 21 records from Scopus, and 12 records from Web of Science, in addition to 44 records identified through other sources. Following the removal of duplicates, 2983 records remained and were subjected to the initial title and abstract screening phase using the Rayyan platform [31], which supports systematic screening and reduces selection bias. At this stage, 2942 records were excluded due to lack of relevance or failure to meet the inclusion criteria. Excluded records comprised unpublished theses, literature reviews, purely medical or psychological studies, diagnostic or epidemiological research, technical studies unrelated to the built environment, as well as books and conference proceedings. The PRISMA flow diagram (Figure 1) presents the study selection process, including screening, exclusion, and eligibility stages leading to the final set of included studies. Non-included sources were used only for contextual support and were not included in the analytical synthesis.

Eligibility Assessment: A total of 41 full-text studies were evaluated for eligibility according to the established inclusion and exclusion criteria. This stage resulted in the exclusion of 12 studies (full text not found (n = 2); studies identified as literature reviews (n = 5); conference proceedings excluded (n = 5)), yielding a final sample of 29 studies included in the qualitative synthesis, as illustrated in the PRISMA flow diagram.

Inclusion and Exclusion Criteria: Inclusion and exclusion criteria were established to ensure methodological consistency and direct alignment with the study objectives, based on the dimensions outlined in Table 1. These criteria encompassed the target population, spatial context, research concept, study type, temporal scope, and publication language, in accordance with PRISMA guidelines for systematic reviews.

Quality Assessment and Screening Reliability: Study quality appraisal was conducted as an independent step following the eligibility assessment to evaluate the strength of the architectural evidence, using a structured criteria checklist covering six core dimensions: clarity of research objectives and spatial context, appropriateness of study design, clarity of sample characteristics, specification of architectural variables, transparency of reported results, and analytical coherence with consideration of potential sources of bias. Appraisal results were used to support interpretation and discussion, without excluding studies based on quality alone unless significant methodological limitations were identified [28,29]. To ensure the reliability of the selection process, both screening stages were carried out by two independent reviewers using the Rayyan platform [31]. Inter-reviewer reliability was assessed using both percentage agreement and Cohen's kappa coefficient. Agreement reached 86.99% during the title and abstract screening stage, with a Cohen's kappa of κ = 0.74, indicating substantial agreement. During the full-text screening stage, agreement reached 90.24%, with a Cohen's kappa of κ = 0.76, also indicating substantial agreement between reviewers.

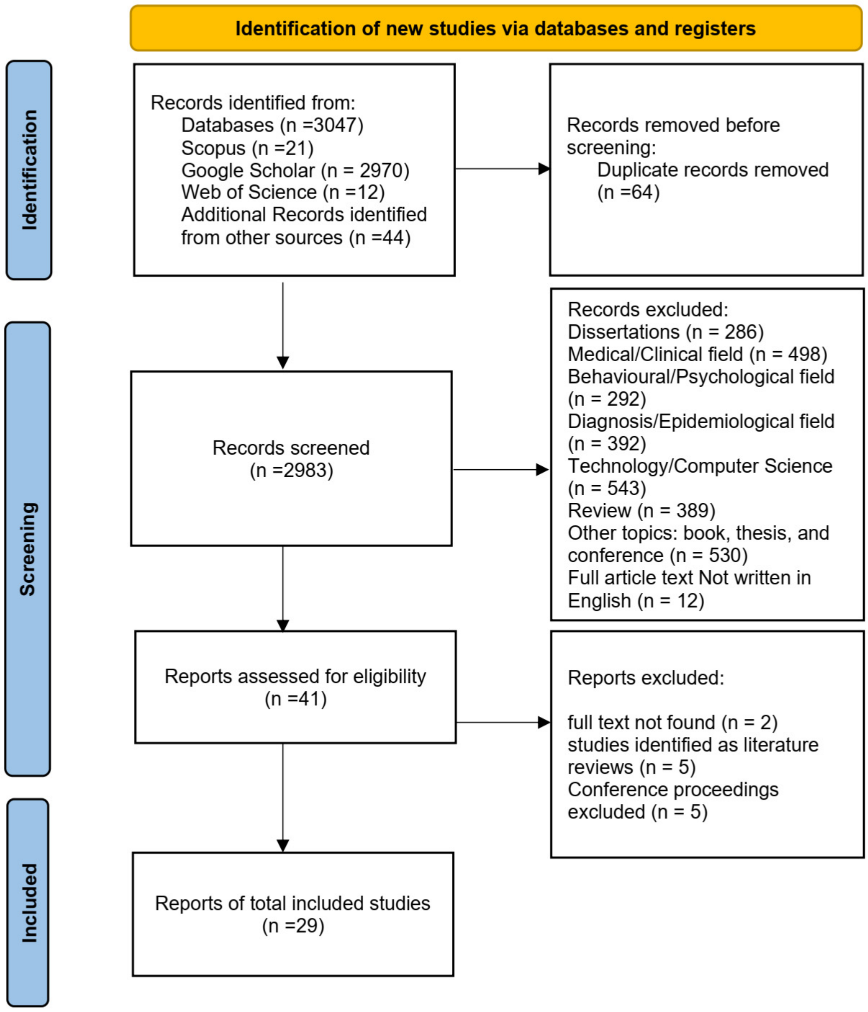

Figure 1. PRISMA flow diagram of the study selection process resulting in 29 included studies.

Table 1. Inclusion and Exclusion Criteria for Study Selection.

Dimension	Inclusion Criteria	Exclusion Criteria
Population	Children with ASD, DS, and/or ADHD, primarily within early childhood (≈3–8 years)	Studies focusing exclusively on typically developing children or adult populations
Setting	Built environments related to early childhood education (e.g., classrooms, schools, learning spaces, sensory rooms, transitional spaces)	Purely clinical, medical, residential, or non-built-environment contexts
Concept/Focus	Sensory-informed, sensory-friendly, interactive, or environmental design approaches addressing sensory, cognitive, emotional, or behavioral responses	Studies addressing medical, diagnostic, therapeutic, or psychological interventions without spatial or architectural relevance
Study Type	Peer-reviewed empirical studies (qualitative, quantitative, or mixed-methods) and applied architectural research	Literature reviews, theoretical commentaries without original analysis, editorials, theses, books, conference proceedings
Time Frame	Publications published between 2016 and 2025	Studies published outside the defined time range
Language	English-language publications	Non-English publications

Data Extraction and Variables Coding: Data were extracted from the included studies using a structured extraction template designed to standardize the extraction process and minimize bias. Extracted data encompassed study characteristics, spatial context, targeted neurodevelopmental group, environmental and architectural variables, sensory dimensions, and behavioral, emotional, and cognitive outcomes. A qualitative thematic synthesis was conducted to categorize and aggregate findings from the 29 included studies into main and sub-themes. The coding process enabled the systematic grouping of environmental variables, sensory dimensions, and reported outcomes into comparable analytical categories. These categories were subsequently synthesized into higher-level themes, which were used to interpret cross-study patterns and to structure the development of the proposed analytical framework and comparative design matrices. Table 2 presents the data extraction framework and coded variables, supporting analytical consistency and linking spatial characteristics with sensory, behavioral, and emotional responses.

Table 2. Data Extraction and Coding Framework Applied to Included Studies (*n* = 29).

Category	Extracted Variables
Study Characteristics	Author(s), year of publication, country of study, study design (qualitative, quantitative, or mixed-methods)
Spatial Setting	Early childhood educational environments, including classrooms, learning spaces, corridors, sensory rooms, and outdoor areas
Target Population	Children with ASD, ADHD, and/or DS
Environmental Design Variables	Lighting conditions, acoustic environment, color schemes, materiality, spatial layout, wayfinding systems, furniture characteristics, and spatial flexibility
Sensory Dimensions Addressed	Visual, auditory, tactile, proprioceptive, and multisensory interactions
Reported Outcomes	Attention and focus, emotional regulation, behavioral responses, engagement, and social interaction
Design Approach	Sensory-informed design, interactive architecture, and biophilic or nature-based strategies
Analytical Contribution	Design principles, architectural frameworks, evaluative criteria, and/or applied design recommendations

3. Results

3.1. Study Selection and PRISMA Outcomes

The PRISMA flow diagram (Figure 1) summarizes the study selection process, resulting in a final sample of 29 studies included in the qualitative synthesis.

3.2. Descriptive Profile of Included Studies

The included studies reflect notable disciplinary diversity, with a predominance of architectural and design-oriented research, alongside multidisciplinary studies situated at the intersection of architecture, interior design, environmental psychology, and applied educational studies related to the built environment. Most studies focused on indoor early childhood learning environments, including classrooms, shared learning spaces, transitional areas, and sensory activity rooms, while outdoor environments such as sensory gardens and open learning spaces were comparatively underrepresented. With respect to neurodevelopmental groups, the findings indicate a pronounced focus on ASD, with more limited representation of studies addressing ADHD and DS, as well as a scarcity of studies integrating multiple neurodevelopmental groups within a comparative architectural framework.

The included studies were classified into four primary categories: (1) applied spatial and case-based evaluations of existing environments; (2) post-occupancy evaluation (POE) studies, specifically examining user–environment interactions and behavioral responses; (3) survey-based and questionnaire studies drawing on the perspectives of teachers, specialists, parents, and, in some cases, children; and (4) qualitative participatory studies incorporating structured observation, interviews, and limited forms of participatory design. A substantial proportion of the studies employed mixed methods, reflecting a growing tendency toward integrated interpretations of built environment interactions and sensory–behavioral responses. In addition, the studies can be differentiated based on their methodological orientation. More specifically, a large subset of the included studies adopts a behavioral approach, focusing on observable user responses and interactions within the built environment, particularly in classroom and post-occupancy contexts. In contrast, a smaller subset of studies employs empirical approaches based on measurable data, including sensory assessments and, in limited cases, physiological or neuro-based indicators. While the review focuses primarily on architectural research, selected interdisciplinary studies were included where they directly inform environmental design variables and sensory–environmental interactions. Table 3 presents the thematic classification of the 29 included studies according to neurodevelopmental focus, spatial context, and design contribution.

Table 3. Thematic Classification of Included Studies by Neurodevelopmental Focus, Spatial Context, and Design Contribution (*n* = 29).

Study Cluster	Neurodevelopmental Focus	Spatial Context	Key Sensory/Environmental Variables	Representative Studies
Autism-focused architectural design frameworks	ASD	Schools, learning environments	Sensory zoning, spatial sequencing, predictability, pedagogical–spatial alignment	[16,18–20,32]
Sensory-responsive interior and classroom design	ASD	Classrooms, learning spaces	Lighting, color, acoustics, materiality, visual–tactile preferences	[22,33–36]
Multisensory environments and sensory control	ASD/mixed neurodevelopmental groups	Sensory rooms, multisensory spaces	Sensory modulation, user control, calming strategies	[37,38]
Movement, furniture, and spatial behavior	ASD	Classrooms, play environments	Seating, movement, spatial connectivity, and behavior regulation	[39–42]
Outdoor and nature-based sensory environments	ASD/mixed	Outdoor learning spaces, sensory gardens	Multisensory outdoor stimulation, nature-based engagement	[43,44]
Attention, noise, and sensory load in learning spaces	ASD/ADHD	Classrooms	Acoustic conditions and noise levels, visual load, attention, and sensory regulation	[14,17,45,46]
DS–oriented environmental assessment	DS	Early childhood facilities, schools	Environmental quality, building biology, perceptual comfort	[15,47]
Inclusive design for intellectual and developmental disabilities	Mixed	Schools, interactive spaces	User-centered spatial strategies, inclusive interaction	[48–50]
Experiential and user-perspective-based studies	ASD/mixed	Residential and public spaces	Lived experience, calm spaces, subjective perception	[25,51]

A quantitative breakdown of the included studies further supports the observed imbalance across neurodevelopmental groups. Of the 29 included studies, 19 focus exclusively on ASD, while only 1 study specifically addresses ADHD, and 2 studies focus on DS. In addition, 7 studies adopt a broader neurodiversity or mixed-group perspective.

3.3. Spatial Contexts and Sensory Design Variables

The results indicate that enclosed educational environments—most notably classrooms—constitute the most extensively examined spatial context in the literature, alongside transitional spaces such as corridors and waiting areas, which are frequently addressed as influential elements in sensory load and behavioral regulation. In contrast, outdoor educational environments were comparatively underrepresented and were most often examined in relation to ASD, highlighting a clear gap in research on outdoor settings that support sensory regulation in early childhood.

The review also indicates a research emphasis on a specific set of environmental variables, including natural and artificial lighting, acoustic properties and noise levels, color schemes and visual contrast, spatial organization and spatial sequencing, visual and sensory stimulus density, and furniture flexibility and adaptability. Some studies examined individual sensory variables in isolation, whereas others adopted multisensory approaches linking environmental conditions to outcomes such as attention, emotional regulation, adaptive behavior, and learning engagement.

3.4. Cross-Cutting Result Patterns

The review findings, supported by the distribution of studies across neurodevelopmental groups and methodological types, highlight several key patterns, including an imbalance in the representation of neurodevelopmental groups, with a clear predominance of studies focusing on ASD, a limited number of comparative studies across multiple groups, and a strong focus on individual sensory elements, often at the expense of spatial sequencing and transition or escape spaces. In addition, much of the literature remains descriptive or prescriptive, with relatively limited development of analytical frameworks or design matrices that can be translated into evidence-based decision-support tools. These patterns inform the subsequent discussion and support the development of the proposed analytical framework and comparative design matrices presented in the following sections.

4. Discussion

The results are discussed by moving beyond the descriptive reporting of the included studies toward interpreting the mechanisms through which environmental variables may influence children's sensory, cognitive, and emotional regulation, culminating in the derivation of analytical design principles that can be coded and evaluated within an architectural framework.

4.1. Interpretive Framework: Sensory Processing, Emotion, and Architecture

Building on the findings of the systematic review and the analysis of the included studies (n = 29), this research employs thematic synthesis as an interpretive analytical lens to organize dispersed architectural literature into interconnected conceptual patterns that enable comparative understanding and support architectural application. This approach extends beyond the aggregation of findings by reframing them to highlight interactions with built environment characteristics, sensory and emotional processing patterns, and the behavioral responses of children with neurodevelopmental disorders.

The thematic synthesis indicates that the concepts of sensory processing, sensory integration, and emotional regulation constitute a shared analytical foundation across the majority of the reviewed studies. Sensory processing describes how the nervous system receives and organizes environmental signals, while sensory integration is considered a crucial need for effective learning and behavioral regulation [4,52]. This interpretation aligns with Ayres' Sensory Integration Theory, which conceptualizes sensory integration as the organization of sensory input for adaptive responses and identifies this process as foundational to learning, behavior, and participation in everyday environments [53]. The literature—including several of the included studies—suggests that children with ASD, DS, and ADHD may exhibit atypical patterns in these processes, rendering them more sensitive to built environment characteristics than typically developing children, as a result of hyper- or hypo-responsiveness to environmental stimuli. These differences are reflected in variations in attention, emotional regulation, and behavior within educational environments [8,14–16,26,50]. Furthermore, the concept of the "spectrum" emphasizes that such responses vary substantially among children, thereby limiting the effectiveness of uniform design solutions [52].

Within this context, Cognitive Load Theory serves as a central interpretive framework, providing a more precise lens for understanding how environmental complexity affects learning. In particular, uncontrolled visual complexity, excessive noise, and unclear spatial organization may be understood as sources of extraneous cognitive load, which exceed children's limited processing capacity and thereby interfere with attention, emotional regulation, and schema formation [54,55]. In this sense, architectural design can be understood as a regulator of cognitive load through the control of environmental complexity. The literature indicates that high visual complexity, uncontrolled noise, and unclear spatial organization impose cognitive demands that exceed a child's processing capacity, leading to distraction, emotional dysregulation, and reduced learning efficiency [14,17,46,56]. Conversely, studies demonstrate that deliberate control of sensory attributes—such as lighting, acoustics, tactile qualities, and spatial sequencing—can play a direct regulatory role in calming the nervous system and enhancing feelings of safety and belonging [2,23,57]. Accordingly, this research adopts these concepts as an analytical lens to link architectural variables with patterns of sensory and emotional responses, as a basis for deriving applicable design principles.

4.2. Design Principles Derived from the Thematic Synthesis

The review findings reveal that sensory–interactive architectural design represents one of the central trends in contemporary literature on early childhood learning environments that support children with neurodevelopmental differences. This approach is defined as a design paradigm that conceptualizes the educational environment as an active sensory–cognitive system, responsive to individual differences through the deliberate integration of lighting, acoustics, color, materials, spatial organization, and, in some cases, interactive technologies [22,37,48,58,59]. The reviewed studies demonstrate a clear shift in architectural discourse from merely describing sensory-related challenges toward the development of evidence-based design responses that address the built environment as an active mediator in supporting learning, behavioral regulation, and emotional regulation, whereby architecture engages sensory and emotional cognition alongside functional performance [18–20,25]. Furthermore, Finnigan emphasizes that variability in sensory response patterns among children with neurodevelopmental differences necessitates learning environments capable of adaptation, rather than assuming a single cognitive or perceptual model [44].

The following principles are grounded in both sensory integration and cognitive load perspectives, linking environmental design variables with patterns of sensory processing, emotional regulation, and cognitive performance. These principles are derived through cross-study synthesis and are intended to function as an integrated architectural framework rather than isolated design guidelines:

1. Sensory control and cognitive load reduction are achieved through minimizing excessive stimuli and employing calming lighting conditions, color palettes, and material selections, thereby supporting sensory balance and emotional regulation [26]. This principle frames environmental control as a mechanism for managing cognitive load rather than as a strategy limited to reducing stimulation.
2. Architectural flexibility and adaptability are facilitated through flexible furniture arrangements and sensory control systems that support autonomy and self-regulation [14,33,50,60]. This principle emphasizes adaptability as a spatial condition that enables user-controlled modulation of sensory input and behavior.
3. Spatial safety and legibility are achieved through clear spatial organization and reduced visual complexity, supporting intuitive orientation within the environment [21]. This spatial clarity reduces uncertainty and supports more stable behavioral responses.
4. Deliberate sensory and emotional engagement is achieved through the controlled integration of natural elements and biophilic design strategies, which may support stress reduction and emotional regulation, while attentional restoration is understood as a

related but distinct cognitive mechanism [12,43,44,61]. This distinction clarifies that biophilic design operates as an environmental strategy, whereas attentional restoration represents a cognitive outcome, with its effects varying across neurodevelopmental profiles depending on the level and type of sensory exposure.

5. Cognitive support and emotional regulation are provided by transitional spaces, calming rooms, and sensory corners that enable gradual transitions between activities without isolating the child from the educational environment [2,20,38]. This principle positions transitional spaces as regulatory interfaces that manage sensory gradation and behavioral adaptation over time.

4.3. Sensory and Emotional Diversity and Architectural Implications

The review findings confirm that early childhood (ages 3–8) represents a critical developmental stage during which patterns of attention, self-regulation, and sensory and emotional responsiveness are formed, at a time when the brain's susceptibility to surrounding environmental stimuli is at its peak [4]. The reviewed literature demonstrates that characteristics of the educational environment—such as lighting, acoustics, spatial organization, and stimulus density—do not function as neutral factors, but rather exert a direct influence on learning as well as behavioral and emotional regulation, particularly among children with differences in sensory processing patterns [17,25]. Within this framework, the analysis of the sensory and emotional needs of children with ASD, DS, and ADHD emerges as an interpretive architectural lens for understanding why a single educational environment may generate divergent—and at times conflicting—responses among these groups, despite their shared spatial context.

The thematic synthesis demonstrates that patterns of sensory processing and emotional regulation not only differ from those observed in typically developing children but also vary significantly across the diagnostic groups themselves, thus limiting the effectiveness of uniform architectural design solutions [14,15,34]. From an architectural perspective, the significance of this variability lies not in medical diagnosis per se, but in the differential sensory and emotional responses elicited by the same spatial characteristics—such as lighting, acoustics, or spatial organization—among children with ASD, DS, and ADHD [12]. This condition necessitates a comparative design logic that acknowledges and responds to these differences, rather than overlooking them.

The literature generally indicates that children with ASD often experience multisensory hypersensitivity to visual, auditory, tactile, proprioceptive, as well as olfactory and gustatory stimuli, rendering the built environment a potential source of overload or threat in the absence of adequate sensory regulation [62–65]. The included studies further confirm that educational environments designed in accordance with autism-friendly design principles—such as reducing visual complexity, controlling acoustics, employing calming color palettes, and providing transitional spaces and sensory rooms—contribute to improved emotional regulation, enhanced concentration, and strengthened social interaction among children with ASD [16,22,32,33,46].

In contrast, the literature indicates that children with DS tend to rely more heavily on visual and tactile inputs than on auditory stimuli and demonstrate more effective learning through direct motor interaction. This is accompanied by potential sensitivity to bright illumination and high noise levels, especially in the presence of deficits in motor coordination and muscle tone regulation [15,47]. The literature further highlights the importance of visual clarity, simplified spatial organization, consistent spatial routines, explicit visual cues, and the provision of areas for privacy and rest in achieving a balanced environment that supports both stimulation and emotional comfort [66].

Concerning children with ADHD, the literature generally indicates heightened sensitivity to dynamic environmental stimuli, such as bright lighting, noise, and visual complexity, which may lead to increased distractibility and acute emotional dysregulation [14,67–69]. The literature further emphasizes that calm, visually organized environments characterized by cohesive color schemes and indirect natural lighting, combined with the provision of flexible spaces that allow for guided movement, contribute to improved attention and self-regulation without suppressing the child's natural need for movement [70].

The comparative analysis demonstrates that appropriate design responses vary according to differences in sensory processing patterns and emotional regulation. While a child with ASD requires a high level of sensory control and clear spatial predictability, a child with DS benefits from structured visual–motor stimulation that supports experiential learning. In contrast, a child with ADHD gains an advantage from visually simple and movement-flexible environments that balance mobility and focused attention. Table 4 presents an analytical comparative matrix of sensory and emotional characteristics and their corresponding design implications for each group, whereas Table 5 provides an integrative synthesis of shared needs derived from the thematic synthesis.

Table 4. Comparative Analytical Matrix of Sensory and Emotional Characteristics and Their Design Implications for Children with ASD, DS, and ADHD.

Target Group	Sensory and Emotional Characteristics	Core Architectural Design Requirements
Autism Spectrum Disorder (ASD)	High and multi-sensory hypersensitivity to stimuli (sound, lighting, touch, odors), difficulties in social communication, a tendency toward withdrawal, and a strong need for spatial predictability and routine.	Multisensory rooms, adjustable natural lighting, calming and non-contrasting colors, matte materials, reduced decoration and visual stimuli, quiet corners and retreat spaces, clearly defined transitional corridors, predictable spatial organization, and carefully regulated integration of natural elements without overstimulation.
Down Syndrome (DS)	Motor and cognitive delay, reduced short-term memory, moderate sensitivity to certain stimuli, clear preference for visual–motor learning, and an increased need for motor and physical support.	Visually clear spaces, direct visual cues, visual and tactile materials that support motor learning, balanced natural lighting, quiet and private areas, safe and easily navigable pathways, and simple spatial organization that supports motor perception and reduces physical strain.
Attention Deficit Hyperactivity Disorder (ADHD)	Impulsivity, rapid distractibility, hyperactivity, reduced sustained attention, sensitivity to noise and visual changes, and variable, unstable sensory responses.	A visually simple, low-stimulation environment, flexible and movement-supportive furniture, active seating, sensory rooms and calming corners, shaded outdoor spaces, adjustable lighting, and soothing transitional corridors that allow organized movement without increasing distraction.

Table 5. Integrative Design Requirements Derived from the Thematic Synthesis of Inclusive Studies on Children with ASD, DS, and ADHD.

Shared Sensory and Emotional Characteristics (ASD + DS + ADHD)	Design Implications and Requirements for Inclusive Learning Environments
High sensitivity and variable levels of tolerance to sensory stimuli (light, sound, touch)	Adjustable natural lighting; non-glossy natural materials; calming and safe color palettes; enhanced acoustic treatment to limit noise; adoption of sensory gradation rather than full sensory deprivation.
Reduced attention span, distractibility, and rapid sensory overload	Visually simple and low-stimulus environments; reduction in visual clutter; clear and direct visual cues; hierarchical spatial organization that supports orientation and wayfinding.
Difficulties in emotional regulation and social interaction	Sensory rooms; calm zones; spaces for guided social interaction; options for partial visual separation without complete isolation; support for social engagement while preserving emotional comfort.
Tendency toward withdrawal, need for privacy, and increased sensitivity to overstimulation.	Safe retreat areas; activity-specific transitional spaces; quiet corners adjacent to learning spaces; spatial proximity without forced exposure; opportunities for voluntary withdrawal.
Hyperactivity, impulsive behavior, and varying movement needs	Flexible furniture; movement-friendly layouts; adaptable spaces that allow structured and guided movement; a balance between activity stimulation and environmental order to reduce chaos.
Delays in short-term memory, fine motor skills, and the need for experiential learning	Integration of natural elements; visually and tactually rich learning zones; support for experiential and kinesthetic learning within architectural spaces.
Need for integrated, multidisciplinary support.	Embedded therapeutic support spaces (sensory integration, speech therapy, occupational therapy, psychological support, and family counseling) are integrated within educational environments without an institutional character.

These matrices demonstrate that identifying shared characteristics does not eliminate zones of conflict between neurodevelopmental groups, as the application of the same architectural variable may produce divergent effects. Accordingly, this study translates the notion of a "zone of conflict" into an operational strategy based on: (1) spatial zoning according to levels of stimulation, (2) sensory gradation through transitional spaces, and (3) the provision of user control to modulate individual responses without compromising overall environmental stability. The analysis concludes that architectural design for inclusive early childhood learning environments should be conceived as a flexible system grounded in sensory gradation, spatial predictability, and behavioral adaptability, enabling accommodation of the wide spectrum of neurodevelopmental differences without transforming the educational environment into a therapeutic or institutional setting.

4.4. Environmental Design Variables and Their Regulatory Effects on Sensory, Cognitive, and Behavioral-Affective Responses

Building on the sensory and emotional variability across ASD, DS, and ADHD, elements of the built environment are interpreted as regulatory environmental variables with varying levels of empirical support across the reviewed studies. These variables modulate the intensity of sensory inputs and reshape cognitive load, thereby directly influencing attention and behavioral–emotional regulation within early childhood learning environments. Primary emphasis is placed on evidence derived from the included studies, while supplementary guidance-oriented sources are incorporated cautiously where direct empirical evidence remains limited.

Accordingly, lighting, color, and acoustics are not treated as isolated esthetic or functional attributes, but rather as components of a mechanism-based synthesis that links: (design variable → regulatory mechanism → expected response pattern by neurodevelopmental group). This framing enables the translation of architectural variables into operational indicators and comparative matrices that support evidence-based design decision-making [18–20].

4.4.1. Lighting and Its Sensory, Cognitive, and Behavioral-Affective Impact

Lighting is among the most influential environmental variables in regulating sensory inputs and cognitive load within early childhood learning environments, due to its direct association with attention, behavior, and emotional regulation, as well as its role in modulating circadian rhythm in children with ASD, DS, and ADHD [16,34,36]. According to the literature, balanced natural illumination is related to greater attention and lower stress, whereas glare, flicker, or poorly managed intensity may lead to increased cognitive load, heightened sensory over-arousal, and distractibility. Several studies report a commonly referenced illuminance range of 300–500 lux to support visual comfort in classroom settings; however, they emphasize that numerical values alone are insufficient without careful consideration of lighting type, distribution, and controllability [34,48]. Supporting guideline-based reviews further suggest that lighting constitutes one of the indoor environmental quality variables most strongly associated with attention and behavioral–emotional regulation in children with ASD, compared to other environmental factors [71]. Accordingly, inclusive school design guidelines recommend the adoption of indirect, controllable lighting systems to mitigate sensory overstimulation and support sensory regulation.

The literature demonstrates clear differential responses across neurodevelopmental groups. Children with ASD and ADHD tend to benefit from diffuse, indirect lighting while avoiding flickering or high-contrast illumination, as such conditions help reduce sensory over-arousal and support attentional stability. In contrast, children with DS may benefit from natural daylight entering through windows as a support for visual perception and spatial orientation, provided that glare is adequately controlled to prevent visual strain [14,16,34,36]. A non-included study (Tufvesson) suggests that direct lighting—such as sunlight falling directly onto work surfaces—may impair concentration among children with DS and ADHD and increase levels of distractibility within classroom settings [12]. Accordingly, supplementary guidance-oriented sources not included in the review suggest that lighting can be treated as a controllable and adaptive regulatory system—manual or smart—that enables dimming and adjustment of color temperature and illuminance according to activity and time, while prioritizing glare reduction and warm, indirect lighting solutions [57]. The literature further suggests that controllability and consistency are generally prioritized over increases in light intensity per se [34]. Overall, the findings indicate that lighting conditions that support visual orientation for children with DS may induce sensory over-stimulation in children with ASD and ADHD, underscoring the need to manage sensory variability rather than standardize lighting schemes.

4.4.2. Colors and Their Sensory, Cognitive, and Behavioral-Affective Impact

Color functions as a regulatory sensory–cognitive variable that influences cognitive load, emotional stability, attention, and spatial perception among children with ASD, DS, and ADHD, extending well beyond its esthetic role. The literature generally indicates that poorly controlled color selections increase visual stimulus density and contribute to over-stimulation and distractibility, whereas limited and balanced color palettes support improved concentration and psychological comfort in an educational environment [34].

The reviewed studies reveal clear differential responses across neurodevelopmental groups. Children with ASD exhibit heightened sensitivity to highly saturated and vivid colors (such as red and yellow), making low-saturation natural hues, neutral color schemes, matte finishes, and the avoidance of sharp visual contrast more appropriate for supporting focus and emotional stability [18,34–36,48]. Similarly, children with ADHD benefit from simple, neutral color environments that reduce visual distractions, with blue and green hues frequently associated with calming hyperactivity and enhancing behavioral regulation and cognitive performance [14,49].

In contrast, color can be strategically employed for children with DS as a regulatory tool for spatial orientation and cognitive support, through the consistent use of calm, moderately saturated, and low-contrast colors to define functions and circulation paths without inducing sensory strain [47]. Overall, the findings suggest that color strategies promoting sensory stability for children with ASD and ADHD may conflict with the orientational role of color for children with DS, necessitating the management of visual contrast through gradation, functional zoning, and selective color application rather than the use of a uniform color scheme.

4.4.3. Materials and Their Sensory, Cognitive, and Behavioral-Affective Impact

Materials constitute a regulatory sensory variable that affects sensory perception, psychological comfort, and emotional regulation among children with ASD, DS, and ADHD, through their tactile qualities, surface texture, and perceived thermal properties. These characteristics shape feelings of safety, attention, and behavioral response patterns within learning environments [35]. The literature indicates that natural and safe materials—such as wood, stone, and cotton-based textiles—support sensory and cognitive stability, whereas industrial materials that are perceptually hard or cold may increase sensory pain and elevate cognitive load, especially among children with heightened sensory sensitivity [22].

The reviewed studies demonstrate clear differential responses across neurodevelopmental groups. Children with ASD often exhibit heightened sensitivity to rough or irregular surfaces, making soft, matte materials more effective in promoting calming effects and behavioral regulation. In addition, cork and wooden flooring have been shown to reduce sensory over-arousal and enhance feelings of safety among children with ASD and ADHD [14,22,35,49]. By contrast, children with DS benefit from visually familiar natural materials, particularly when employed along functional pathways and orientational cues, as these materials support spatial perception, reduce visual distraction, and enhance learning through clear sensory signals [47].

The literature further recommends avoiding materials with harmful emissions due to their negative impact on indoor air quality and public health, a consideration of particular importance for children with ADHD, given their heightened environmental sensitivity [48]. Supplementary guidance-oriented sources not included in the review sample suggest the use of matte, impact-resistant, non-slip materials with rounded edges and ease of maintenance, especially within sensory spaces and calming rooms, as such characteristics can contribute to enhanced safety and emotional stability [57]. A balanced integration of hard and soft surfaces is also reported to support a stable sensory environment that facilitates perception and interaction without inducing sensory overload [44]. Accordingly, materials are treated not as isolated esthetic elements, but as regulatory variables for reducing sensory load and enhancing safety and emotional stability through their coherent integration with other design components.

4.4.4. Acoustics and Their Sensory, Cognitive, and Behavioral-Affective Impact

Acoustics represent one of the most influential built environment variables affecting sensory and behavioral regulation among children with ASD, DS, and ADHD, due to their direct association with attention, cognitive processing, and emotional regulation. Exposure to sudden noise, sharp sounds, or excessive reverberation is associated with increased distractibility, anxiety, sensory over-arousal, and behavioral withdrawal, thereby undermining interaction and adaptive behavior within educational environments [16,17,45]. Children with ASD exhibit heightened auditory sensitivity, rendering noisy environments a significant stressor that may escalate to physically distressing responses or sensory overload episodes. This sensitivity explains the extensive focus within the literature on acoustics as one of the most impactful dimensions of indoor environmental quality in neurodiversity-oriented research [19,45,50].

Evidence further suggests that improved acoustic control supports attention in children with DS by reducing auditory distraction within classroom settings [47]. Similarly, Mostafa's studies indicate that noise reduction contributes to greater attention, less repetitive behaviors, and improved emotional stability among children with ASD [18,20]. In contrast, children with ADHD have a higher sensitivity to repetitive or unpredictable sounds, which impair sustained concentration and encourage impulsive behavior, and therefore require stable and predictable acoustic surroundings [14].

The literature indicates that effective acoustic control relies on reducing noise sources and reverberation through the use of sound-absorbing materials, avoiding reflective surfaces, and zoning spaces according to levels of auditory stimulation in ways that provide helpful acoustic gradation for transitions between activities [17,18,20]. The use of impact-absorbing flooring, acoustically treated ceilings, heavy fabrics and curtains, and sound-insulated windows and doors is further recommended, alongside avoiding sharp, high ceilings that amplify reverberation and auditory load [14,19]. Some studies suggest that maintaining noise levels below approximately 50 dB supports emotional stability, learning engagement, and reduces compulsive or aggressive behaviors [34].

Conversely, supplementary guidance-based evidence not included in the review sample suggests that the integration of calming sounds—such as nature sounds or low-intensity music—may support attention and emotional regulation when carefully controlled to avoid over-stimulation [72]. The comparative analysis demonstrates that the acoustic environment involves a clear regulatory conflict: children with ASD require low-noise, tightly controlled auditory environments; children with DS benefit from acoustically warm and stable settings; while children with ADHD require a balance between minimizing unpredictable noise and allowing structured auditory stimulation. This necessitates managing auditory rhythm through gradation, functional zoning, and control of sound sources, rather than relying on complete silence.

4.4.5. Ventilation and Scents: Their Sensory, Cognitive, and Behavioral-Affective Impact

Ventilation and indoor air quality function as direct regulatory variables in supporting attention, emotional stability, and cognitive performance among children with ASD, DS, and ADHD. Poor indoor air quality and insufficient air renewal rates are associated with increased cognitive load, reduced cognitive performance, and heightened distractibility and sensory fatigue, thereby diminishing learning readiness and behavioral engagement within educational environments [73,74]. Sensitivity to subtle environmental changes is particularly pronounced among these groups, rendering air quality a critical factor during early childhood, before the full maturation of self-regulatory mechanisms [75].

Supplementary guidance-oriented evidence not included in the review sample suggests that sudden changes in airflow, ventilation rates, or associated odors may elicit maladaptive sensory responses—ranging from distraction and discomfort to behavioral withdrawal—especially among children with heightened olfactory sensitivity, a condition commonly reported in ASD [13,23]. In this regard, Bahrami and Nejad (2024) report that instability in the olfactory environment, whether due to abrupt changes in air quality or the introduction of strong and unpredictable odors, disrupts adaptation in children with ASD and increases the likelihood of sensory over-arousal or behavioral rejection [16].

Accordingly, the literature suggests adopting stable and gradual ventilation strategies—natural or mechanical—that ensure adequate air renewal without inducing sensory shock resulting from sudden changes in airflow or odor. These findings further highlight the importance of functional separation between classrooms and potential odor sources (e.g., kitchens, restrooms, and cleaning areas) to maintain a predictable olfactory environment. Conversely, some studies suggest that subtle, carefully controlled natural scents may support calming and attentional processes when introduced cautiously within a stable olfactory context, without becoming repetitive or unpredictable stimuli [74,76].

Overall, ventilation and the olfactory environment can be understood as key regulatory variables within this context, where stability—rather than intensity—constitutes the decisive factor in reducing sensory load and supporting emotional regulation. Unpredictable airflow or odors are particularly likely to induce sensory over-arousal among children with ASD, underscoring the need for gradual ventilation strategies and functional separation of odor sources to ensure stable, inclusive learning environments for children with ASD, DS, and ADHD.

4.4.6. Natural Elements and Sensory Gardens: Their Sensory, Cognitive, and Behavioral-Affective Impact

Natural elements and sensory gardens function as effective regulatory variables that support sensory balance, emotional regulation, and cognitive performance among children with ASD, DS, and ADHD. The systematic integration of vegetation, natural materials, and daylight contributes to stress reduction and enhances concentration and social engagement, in alignment with biophilic design principles, while Attention Restoration Theory (ART) provides a related explanatory framework for cognitive effects [2,39,49]. The literature indicates that structured and non-excessive exposure to nature improves attention and calms behavior in children with ADHD, reduces repetitive behaviors and supports social interaction in children with ASD when stimulation levels are carefully controlled, and benefits children with DS by serving as a sensory–motor cognitive mediator that supports spatial perception, behavioral regulation, and experiential learning within familiar and safe environments [16,44].

According to studies, the success of sensory gardens depends not only on the presence of natural elements but also on their structure and functional integration through sensory gradation, ease of access, and spatial continuity with indoor learning spaces. The inclusion of supportive features—such as water elements, natural sounds, and varied textures—within safe and clearly bounded limits is important in preventing sensory overstimulation [43,47]. Accordingly, natural elements and sensory gardens are treated as core regulatory tools for reducing sensory load and enhancing emotional regulation, learning engagement, and self-discipline, rather than as isolated esthetic features, within the sensory–interactive architectural design system for supportive early childhood learning environments.

4.4.7. Learning Space Design and Its Sensory, Cognitive, and Behavioral-Affective Impact

The organization of educational spaces constitutes a pivotal regulatory variable in supporting sensory stability and behavioral–emotional regulation among children with ASD, DS, and ADHD, given their heightened sensitivity to environmental stimuli and their need for environments that are clear, predictable, and low in spatial ambiguity. The literature consistently emphasizes that clarity of spatial geography, sequencing of activities, and predictability of movement paths reduce anxiety and enhance autonomy and behavioral engagement [18,19,41,42,51]. Furthermore, clear sensory–spatial zoning and the gradual separation between high-stimulation zones and focus-oriented areas—mediated through transitional spaces and non-rigid visual boundaries—are identified as critical mechanisms for preventing sensory interference and supporting emotional adaptation [16,20,22].

Architectural flexibility—manifested through adjustable furniture, controllable lighting, visual separation, and the reduction in excessive ornamentation—emerges as a key mechanism for supporting individual responsiveness and enhancing self-regulation [33]. In addition, calming and sensory retreat zones, spatial interactions aligned with the child's scale, and the minimization of high-movement visual exposure contribute to reducing distraction and sensory stress [19,20,38,51]. Transitional areas further support sensory gradation and the recalibration of emotional states before shifts between activities [18,49].

The literature also highlights the importance of low-density, simplified classroom environments, as well as the effectiveness of multisensory rooms when integrated within a well-organized spatial system [19,20,22]. Comparative analysis reveals a regulatory tension between the need for strict spatial stability among children with ASD, the visually and motorically open environments that support learning in children with DS, and the structured movement flexibility required by children with ADHD. This confirms that effective design responses should not rely on a single spatial model, but rather on managing variability through functional zoning, sensory gradation, and a balanced integration of stability and flexibility within the same educational environment.

4.4.8. Wayfinding and Navigation: Their Sensory, Cognitive, and Behavioral-Affective Impact

Wayfinding and navigation constitute pivotal regulatory variables for supporting spatial cognition, visual memory, functional independence, and reducing anxiety and sensory load among children with ASD, DS, and ADHD. The literature consistently confirms that clear and predictable wayfinding systems reduce spatial ambiguity and enhance feelings of control and behavioral engagement, particularly among children with heightened sensitivity to spatial changes [19,44]. Children with DS rely more heavily on color coding and specific visual cues to enable spatial orientation and independent navigation, but children with ASD need easy routes, spatial consistency, and clearly structured surroundings to avoid stress and sensory over-arousal [16,19,47]. In addition, both ASD and ADHD groups benefit from low-stimulation transitional zones that facilitate emotional state recalibration and reduce sensory load during movement between spaces [19,49].

From a sensory perspective, the literature suggests avoiding intense backlighting in corridors, as it may cause visual glare and increase distractibility. Instead, the use of directed and graduated lighting, along with external visual reference points—such as gardens or trees—is encouraged, as these elements serve as visual anchors that support positive spatial orientation and strengthen place attachment. In addition, maintaining a unified visual design language throughout the building—in terms of materials, colors, and lighting—contributes to spatial continuity and reduces the cognitive load associated with navigation [19].

Comparative analysis reveals a regulatory conflict whereby the density of visual cues that support wayfinding for children with DS may become a source of sensory over-arousal and spatial confusion for children with ASD and ADHD. This finding reinforces that effective design responses should not rely on a standardized wayfinding system, but rather on managing perceptual variability through route simplification, graduated visual cues, a coherent design language, and clear functional zoning that balances spatial cognition support with sensory stability.

4.4.9. Furnishings and Equipment: Their Sensory, Cognitive, and Behavioral-Affective Impact

Furniture and fixtures constitute an interactive regulatory variable that influences the modulation of sensory and cognitive load, thereby affecting attention, behavior, and emotional regulation among children with ASD, DS, and ADHD. The literature indicates that furniture serves not merely a physical function, but operates as a regulatory tool that structures movement rhythms, reduces distractibility, and supports behavioral–emotional regulation [49]. Children with ASD and ADHD particularly benefit from movement-supportive and adjustable furniture, which can help channel motor energy in an organized manner and enhance attention without imposing physical restraints [18,40].

Studies on children with ASD propose the use of flexible and movable furniture without sharp edges, as well as closed and organized storage solutions that decrease visual clutter, thereby supporting spatial predictability and emotional soothing [20,48]. In contrast, children with DS benefit from stable and comfortable furniture supported by visual and guidance elements that facilitate spatial cognition and independent navigation, drawing on visual–motor learning strategies [15,47]. Moreover, the use of soft and natural materials, sound-absorbing furniture, and furniture employed as flexible spatial dividers can contribute to reducing sensory load and supporting sensory privacy without spatial isolation, thereby enhancing autonomy and behavioral engagement within inclusive learning environments [35,40,47].

4.4.10. Art and Its Sensory, Cognitive, and Behavioral-Affective Impact

Art, viewed as a sensory-cognitive regulatory medium, contributes to nonverbal expression, emotional regulation, stress reduction, and enhanced communication and behavioral engagement among children with ASD, DS, and ADHD, particularly in cases where verbal expression or emotional regulation is challenging. Supplementary guidance-oriented evidence not included in the review sample suggests that structured art activities—such as drawing, sculpting, and printmaking—can act as directed sensory mediators that help calm the nervous system and reduce aggressive behaviors through gradual interaction with materials, colors, and fine motor movements [24].

The evidence further indicates the importance of designing art spaces as low-stimulation environments with clear spatial organization and well-defined functions, minimizing unnecessary decoration and extraneous stimuli, and providing designated workstations that foster a sense of achievement, self-efficacy, and autonomy, especially among children with ASD and DS. The use of indirect natural lighting can additionally support visual comfort and reduce visual strain associated with artificial lighting and high-contrast conditions [24]. Accordingly, art is integrated as a multidimensional design component within educational environments to support self-regulation, guided social interaction, and a sense of competence and belonging, within an evidence-based sensory–interactive architectural design framework.

4.4.11. Interactive Technology and Its Sensory, Cognitive, and Behavioral-Affective Impact

Interactive technology—based on supplementary guidance-oriented literature not included in the review sample—may be considered a supportive variable for sensory regulation and cognitive–behavioral engagement among children with ASD, DS, and ADHD, through directed visual–auditory–motor stimulation that enhances attention, social interaction, and emotional skill development, provided that such technologies are carefully designed and controlled to avoid sensory overload [77,78]. Evidence suggests that tools such as virtual reality, interactive displays, and multisensory rooms may support improvements in learning outcomes and reduce stereotypical behaviors, particularly among children with ASD, when integrated within architecturally balanced, sensory-regulated educational environments rather than applied as isolated technological interventions [22].

Further evidence from recent supplementary studies suggests that the adaptive use of technology in response to individual sensory differences may support additional neurodevelopmental groups. Interactive floors and movement-based digital tools help children with ADHD channel motor energy in a structured manner, thereby improving attention and behavioral engagement [79]. Similarly, multisensory learning approaches based on games and digital applications support academic comprehension and social skill development among children with DS by integrating visual, motor, and tactile interaction within organized educational contexts [80,81]. Wearable devices and smart sensing technologies may further contribute to environmental personalization, enhanced independence, and real-time spatial feedback that supports self-regulation and emotional control [44,82]. Across the literature, technological effectiveness appears to depend not on intensity or density, but on controllability, gradation, and integration with adjustable architectural elements—such as lighting, acoustics, furniture, and wayfinding—thereby maintaining sensory stability and preventing excessive cognitive load [14,22,48]. Accordingly, interactive technology is conceptualized not as an isolated stimulatory feature, but as a supportive regulatory variable within the sensory–interactive architectural design framework.

4.4.12. Safety and Security: Their Sensory, Cognitive, and Behavioral-Affective Impact

Safety represents a key design variable in inclusive educational environments for children with ASD, DS, and ADHD, given their limited risk perception, heightened sensory sensitivity, and the associated emotional strain and unpredictable behaviors [18,33]. The literature indicates that effective safety is achieved through integrated, preventive, and non–sensory-provoking strategies, including safe furniture and non-toxic materials, slip-resistant surfaces, reduced climbable elements, and enhanced indirect visual supervision without compromising privacy [18,19,48]. Studies focusing on ASD, in particular, indicate the need for unobtrusive measures to mitigate elopement and impulsive behavior—such as concealed barriers, silent alerts, and carefully calibrated visual transparency—alongside shock-absorbing flooring, low-rise building configurations, and controlled lighting to avoid sensory over-arousal [51]. Overall, the literature suggests that inclusive safety should not rely on isolation or excessive control, but rather on a carefully balanced integration of autonomy and regulation through clear spatial hierarchies and supportive smart systems, thereby preserving sensory stability, trust, and a sense of belonging within early childhood learning environments.

The discussion demonstrates that the evidence derived from the included studies (*n* = 29) does not support "one-size-fits-all" design solutions; rather, it suggests that environmental variables operate as an integrated regulatory system that generates differentiated sensory–cognitive–emotional responses across ASD, DS, and ADHD. This variability necessitates a comparative design logic capable of managing zones of convergence and conflict among these neurodevelopmental profiles. Accordingly, the following section builds upon this interpretive synthesis to develop a structured analytical framework by translating the findings into a codified structure and comparative matrices, thereby supporting the systematic interpretation of design-related insights for inclusive early childhood learning environments.

5. Integrated Framework and Analytical Structuring

This section represents the conceptual and methodological transition of the study from interpreting the findings derived from the thematic synthesis to constructing a more explicit analytical architectural framework that transforms the literature on sensory design, inclusive learning environments, and neurodevelopmental differences into a comparative and decision-support analytical system. Building upon the results presented in Section 4, elements of the built environment are not treated as isolated physical attributes, but rather as Regulatory Environmental Variables that are understood to shape sensory load, cognitive regulation, and behavioral–emotional responses among children with ASD, DS, and ADHD.

Rather than treating lighting, color, or acoustics as isolated and generalized design recommendations, the study reconceptualizes them as Regulatory Environmental Design Variables evaluated according to their functional role in: (1) modulating the intensity and variability of sensory stimuli, (2) reducing cognitive load, (3) enhancing spatial predictability and perceived control, and (4) supporting emotional and behavioral regulation. Accordingly, the impact of each element derives not merely from its physical presence, but from how it operates regulatorily within the spatial context. Lighting is thus understood as a mechanism for managing visual load and circadian rhythm; acoustics as a system for regulating auditory pressure and sensory arousal; and spatial organization as a mediator of predictability, routine, and autonomy. The findings further demonstrate that differences across ASD, DS, and ADHD are not inherent to the environmental element itself, but to its regulatory function and the conflicts that may emerge when a single solution is generalized across distinct neurodevelopmental profiles. Consequently, the study advances a graduated and controllable regulatory logic in place of universalized design prescriptions.

To analytically structure this conceptual shift, the study develops an interpretive analytical model termed the Sensory–Interactive Architectural Framework (SIAF), designed to structure the interaction between neurodevelopmental characteristics, environmental variables, and patterns of sensory–emotional response within early childhood learning environments. The SIAF does not assume automatic alignment between the sensory needs of different neurodevelopmental groups; rather, it explicitly addresses zones of overlap and conflict as architectural design conditions that must be actively managed rather than overlooked or simplified. The framework is structured into four interrelated layers (Figure 2):

1. Neurodevelopmental Profiles—encompassing ASD, DS, and ADHD, reinterpreted not merely as medical diagnostic categories but as distinct patterns of interaction with the built environment.
2. Sensory–Emotional Response Patterns—representing the dynamic responses that emerge through environmental interaction, including hyper- or hypo-sensory sensitivity, cognitive load, emotional regulation, and interactive behavioral expression.
3. Regulatory Environmental Design Variables—comprising architectural variables capable of modulating these responses, such as sensory load regulators, mechanisms of spatial predictability, and design elements that support safety and emotional regulation.
4. Behavioral–Cognitive Outcomes—reflecting the anticipated outcomes of regulatory design interventions, including improved attention, reduced hyper-arousal, enhanced self-regulation, and strengthened educational engagement and functional independence.

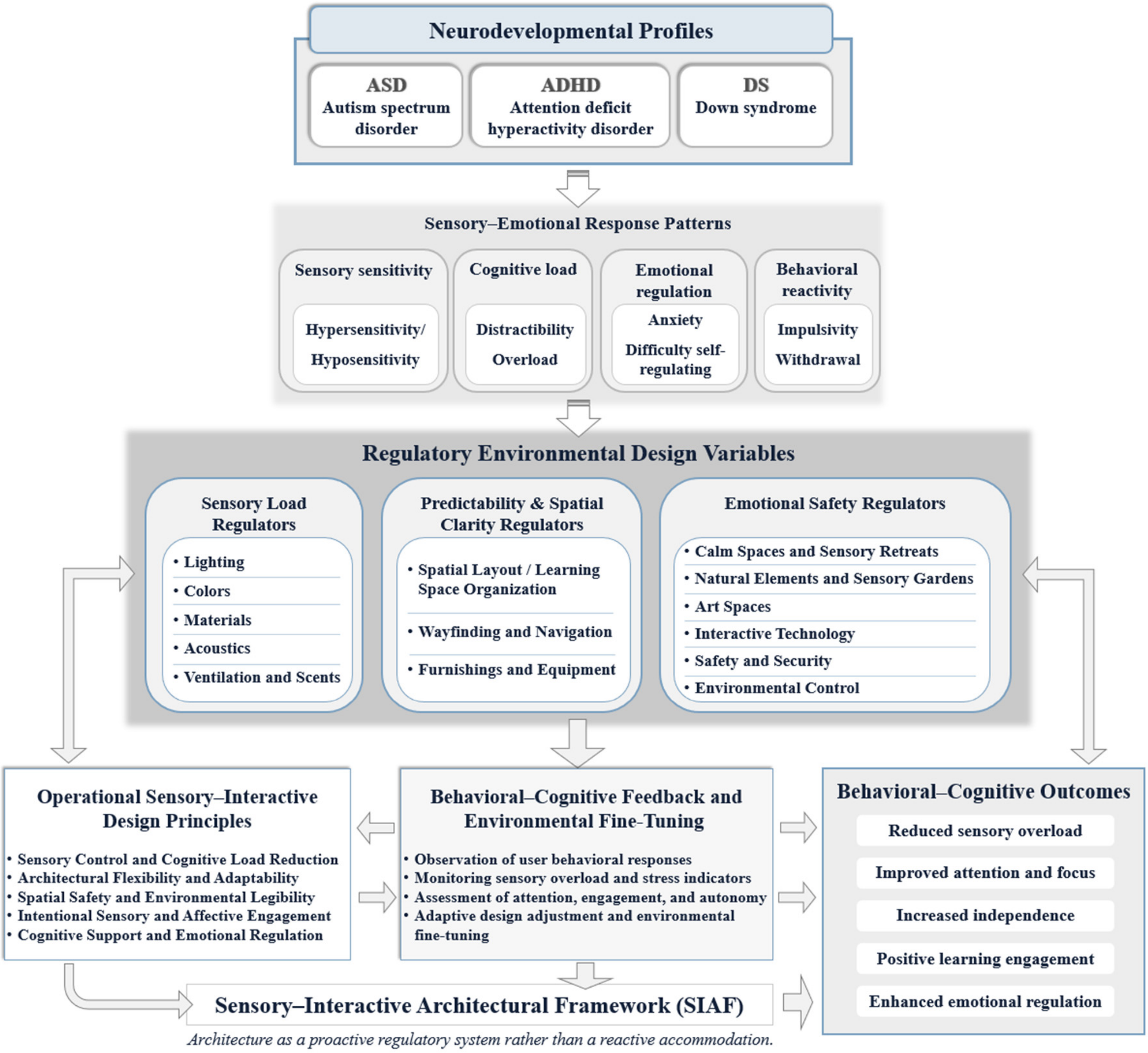

Figure 2. The Sensory–Interactive Architectural Framework (SIAF) illustrates the regulatory interactions between neurodevelopmental profiles (ASD, ADHD, and DS), sensory–emotional response patterns, environmental design variables, and the resulting behavioral–cognitive outcomes in inclusive early childhood learning environments.

The SIAF further incorporates a behavioral–cognitive feedback component for post-occupancy refinement, conceptualized as an iterative mechanism through which regulatory variables may be recalibrated based on observed response patterns and indicators of sensory load, attention, and engagement, without claiming empirical field implementation within the scope of this review.

Importantly, the SIAF does not assume a linear causal interaction between a design element and behavioral outcomes; rather, it conceptualizes architectural design as a regulatory mediator operating in relation to stimulus intensity, child-specific capacities, and the spatial context of use. In this way, the framework shifts the architectural discourse from the question, "What is the optimal design element?" to a more critical inquiry: "How does this element function regulatorily, and for which neurodevelopmental profile?"

To further structure the SIAF as an analytical and interpretive framework, the study adopts a coding and analytical matrix logic, whereby each environmental variable is coded according to its primary regulatory function and subsequently linked to its relative suitability across ASD, DS, and ADHD profiles. These codes are further associated with anticipated effects at the sensory, cognitive, and behavioral–emotional levels (e.g., reduction in sensory load, enhancement of spatial predictability, improvement of attention, and regulation of movement). Based on the comparative analysis of zones of convergence and conflict, an integrated regulatory–conflict coding matrix (Table 6) was developed as an analytical synthesis designed to support the systematic tracing of: (1) shared compatibilities, (2) potential points of conflict, and (3) design strategies for managing these tensions within a coherent framework. At this stage, the matrix may be understood as a conceptual–analytical structure supporting comparative interpretation, rather than a fully validated assessment instrument, as the proposed codes do not yet incorporate empirically tested thresholds, scoring criteria, or standardized measurement protocols. In this way, the SIAF and its accompanying matrix provide a structured interpretive basis for comparative literature analysis and the preliminary formulation of design-oriented analytical categories for inclusive early childhood learning environments. They are presented here as interpretive and comparative proposals that require future empirical validation before use as fully operational evaluation indicators in practice.

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Table 6. Integrated Regulatory–Conflict Analytical Matrix for Inclusive Early Childhood Environments (ASD–DS–ADHD).

Regulatory Dimension	Environmental Variable	ASD Needs/Sensory–Emotional Profile	DS Needs/Sensory–Emotional Profile	ADHD Needs/Sensory–Emotional Profile	Common Compatibility Across ASD, DS, and ADHD	Potential Conflict Zone	Conflict Management Strategy	Design Code/Interpretive Indicator
Sensory Load Regulation	Lighting	High sensitivity to glare and flicker; preference for diffuse, indirect lighting; strong need for controllability to stabilize visual input	Natural light supports visual perception and spatial orientation; glare control is essential.	Sensitive to sudden changes in intensity and contrast; requires adjustable lighting	Stable, controllable, low-glare lighting with minimized flicker	Natural daylight may support DS visually, but may trigger over-arousal or distraction in ASD and ADHD	Zoning of lighting levels; graduated transition spaces; localized lighting control (dimming systems, blinds, color temperature adjustment)	L1 Non-glare indirect lighting in learning/quiet zones. L2 Flicker-free luminaires. L3 Daylight with controllable shading at DS-oriented wayfinding points. L4 Adjustable illuminance (task-based).
	Color	Avoid highly saturated and high-contrast colors; preference for muted, low-saturation, matte finishes.	Color as a spatial orientation tool; moderate tones to differentiate functions	Simple, neutral palettes that reduce distraction; blue and green tones may support calming	Soft, low-saturation palettes with controlled color gradation; avoidance of sharp contrast	Strong color coding, beneficial for DS, may create sensory overload or distraction in ASD and ADHD.	Selective functional color coding; reduction in decorative clutter; hierarchical color sequencing; control of saturation and contrast	C1 Neutral-first palette; limited accent colors by function only. C2 Matte finishes; avoid high saturation in classrooms. C3 Blue/green tones in focus zones C4 Selective color coding at wayfinding nodes only
	Materials (tactile/visual)	Preference for smooth, organized surfaces; avoidance of rough textures and excessive reflectivity; perceptually warm materials	Familiar natural materials; tactile cues may support orientation and cognition	Avoid cold or harsh industrial materials; preference for balanced tactile input	Natural, safe, non-reflective materials; balanced textures; low-emission finishes	Overuse of tactile cues for DS may increase sensory load in ASD/ADHD if not regulated	Hierarchical material sequencing with localized tactile markers, controlled texture and contrast, and low-emission, easy-to-clean finishes.	M1 Matte, low-texture primary finishes in classrooms. M2 Tactile/material landmarks only at navigation nodes. M3 Slip-resistant and impact-safe edges; easy-to-clean finishes; low-VOC materials M4 Use of natural, familiar materials appropriate to children
	Acoustics	High auditory sensitivity; strong need to reduce noise and reverberation	A stable and warm acoustic environment that supports attention without sudden auditory disturbances	Rapid distraction with repetitive or unpredictable sounds; requires auditory stability while avoiding reverberation	Reduction in unexpected noise; sound absorption; echo control; separation of vibration sources	Complete silence may not always be practical; DS may benefit from a less rigid acoustic environment; excessive noise may trigger stress in ASD; ADHD requires balance	Acoustic gradation between spaces; functional zoning according to stimulation level; control of sound sources	A1 Target low reverberation via absorptive ceilings/walls. A2 Shock-absorbing flooring A3 Noise sources are buffered (toilets/kitchens separated). A4 Quiet rooms with enhanced acoustic control (ASD/ADHD). A5 Noise levels $\leq$ ~50 dB in learning zones A6 Optional low-intensity nature sounds only in designated zones with control.
	Ventilation and Scents	High sensitivity to sudden changes in airflow and odors; strong impact due to lack of olfactory stability	Stable air quality that reduces distraction and supports comfort; separation of odor sources	Sensitivity to physical environmental factors; improved attention with good air quality; avoidance of strong or sudden odors	Stable ventilation; separation of odor sources; gradual air renewal without sensory "shocks."	"Calming" scents may support some individuals but may become unpredictable triggers for others, particularly those with ASD	Gradual ventilation; stable airflow; functional separation of odor sources	V1 Separate odor sources (toilets/cleaning) from learning zones. V2 Stable airflow; avoid drafts. V3 No strong artificial scents; optional mild natural scents only in designated therapy zones.

Table 6. *Cont.*

Regulatory Dimension	Environmental Variable	ASD Needs/Sensory–Emotional Profile	DS Needs/Sensory–Emotional Profile	ADHD Needs/Sensory–Emotional Profile	Common Compatibility Across ASD, DS, and ADHD	Potential Conflict Zone	Conflict Management Strategy	Design Code/Interpretive Indicator
Predictability and Spatial Clarity Regulators	Spatial Layout/ Learning Space Organization	Requires clear spatial geography, fixed sequencing, and consistent spatial routines; reduction in complexity and change.	Direct visual planning and safe pathways; environments that support visual–motor learning.	Flexibility that allows organized movement without chaos; configuration that permits reorganization within clear rules	Clear sensory–spatial zoning; separation of high-stimulation and focus areas; transitional zones.	Spatial rigidity is essential for ASD; higher flexibility is needed for ADHD; DS benefits from experiential learning spaces.	Zoning according to stimulation level: dual-mode rooms (fixed/flexible)	SL1 Clear functional zoning (high/low stimulation). SL2 Transitional zones between activity types. SL3 ASD-oriented stable routes + ADHD-oriented movement pockets. SL4 Controlled visual access to outdoors with shading.
	Wayfinding and Navigation	Simple, non-intersecting routes; spatial continuity	High benefit from color coding and visual markers	Concise signage that reduces ambiguity without increasing distraction	Clear pathways; functional signage; consistent design language	High density of visual cues beneficial for DS may become visual overload for ASD and ADHD if not controlled	Hierarchical sequencing of signage; display only when needed	W1 Minimal, high-salience signage at decision points only. W2 Color-coding is limited to DS landmarks. W3 Consistent material/lighting language along routes.
	Furnishings and Equipment	Preference for organized furniture and closed storage units to reduce visual clutter; safe, rounded edges	Stable and comfortable furniture that supports individual and group activities; visual cues on storage units	Benefits from active seating and movement-oriented furniture while maintaining spatial order	Safe, adjustable furniture; flexible configuration without spatial isolation	Active/movement seating is beneficial for ADHD, but may increase distraction in ASD if not structured and regulated	Controlled flexibility; structured movement seating; activity-based zoning; organized storage systems	F1 Closed storage; clutter control. F2 Active seating only in designated ADHD movement zones. F3 Rounded edges, stable furniture in core classrooms.
Emotional Safety and Regulation Regulators	Calm Spaces/ Sensory Retreat	Necessary proximity and functional accessibility; low sensory stimulation; safe withdrawal without isolation	Supports privacy and comfort with clear accessibility and minimal spatial complexity	Necessary to reduce hyperactivity during overstimulation; a short-term calming space	Availability of calming spaces and transitional zones that support emotional reset	Excessive isolation may weaken inclusion; absence may increase sensory overload	Near-class micro-retreats; semi-visual separation; time-bounded use	CS1 Calm corner within visual proximity of the learning space. CS2 Semi-transparent partitions (privacy without isolation). CS3 Sensory-neutral material/lighting package.
	Natural Elements/ Sensory Gardens	Calming effect and reduction in stereotypical behaviors, provided stimulation is regulated, and excessive exposure is avoided	Cognitive–motor medium that supports experiential learning and safe movement	Improved attention and reduction in hyperactivity	Integration of nature as an organized sensory system; emotional access; safe access; functional integration with learning	"Untamed" or uncontrolled nature (water/sounds/colors) may cause overstimulation for some individuals with ASD	Clear sensory gradation; zoning of garden areas according to stimulation levels; gradual integration of natural elements; control of element density	N1 Shaded, controlled sensory garden with graded stimuli. N2 Direct supervised access from classrooms. N3 Avoid high-stimulus features unless zoned/controlled.
	Art Spaces	Requires low-stimulation artistic environments; clear functional definition; indirect lighting	Supports expression and motor learning when stations are clear and direct	Supports emotional release and energy regulation when stimuli and transitions are controlled	Art as a medium for non-verbal expression with controlled visual and lighting conditions	Visual clutter or decorative excess in art spaces may increase distraction and sensory overload	Clear stations; visual clutter control; lighting stability; safe materials	AR1 Clearly defined art workstations. AR2 Non-glare indirect lighting. AR3 Controlled display areas (avoid wall overload).
	Interactive Technology	Beneficial if controlled and non-excessive; requires integration with light and sound control	Supports multisensory learning through structured applications and games (visual–motor–tactile)	Supports guided movement and attention (interactive floors and motor engagement) when introduced gradually	Technology as a controllable regulatory system, not an additional complexity	High technological density may increase cognitive load in ASD and ADHD if not carefully regulated	Technological zoning; adjustable intensity; session-based use; integration with environmental control	IT1 Interactive technology is only in designated rooms/zones. IT2 Intensity control (light/sound). IT3 Clear start/stop cues and limited duration. IT4 Wearables/sensors are optional for personalization with privacy safeguards.
	Environmental Safety/Security	Risk of elopement during overstimulation; requires non-obtrusive solutions (concealed barriers and silent alerts)	Reduced risk perception; requires clear physical protection (safe glazing, slip resistance, rounded edges)	Impulsivity requires minimized hazards with structured movement opportunities	Physical and psychological safety without additional sensory burden; indirect visual supervision	Strict security measures may increase anxiety in ASD if perceived as institutional	Invisible safety strategies; hierarchy of spaces; soft barriers; clear supervision lines	SS1 Rounded edges, slip-resistant floors. SS2 Controlled exits with silent alerts. SS3 No hidden corners; passive supervision. SS4 Low-rise preference where applicable.
	Environmental Control (user adjustability)	High need for control over light, sound, and privacy	Simple, non-complex control systems	Supports self-regulation without distraction (controlled access to lighting or acoustic adjustment)	Sense of control through simple solutions that reduce stress	Individual control may create sensory inconsistency for others	Localized control; pre-set configurations according to activity	EC1 Local dimming/shading per zone. EC2 Acoustic/visual partitions adjustable. EC3 Pre-set scenes (focus/play/calm).

Table 6 should be read as an interpretive coding matrix rather than a quantitative scoring tool. Each code identifies a proposed design condition derived from cross-study synthesis and links it to a regulatory design intention, a potential zone of conflict, and a corresponding management strategy. Accordingly, the codes are intended to support comparative reading and conceptual mapping at the level of design logic, rather than functioning as fully operational evaluation indicators.

This matrix reflects the analytical logic adopted by the study, in which elements of the built environment are reframed not as isolated design features but as regulatory dimensions interpreted according to their role in managing sensory load, improving spatial predictability, supporting emotional regulation, and shaping behavioral and learning outcomes. In this manner, the SIAF and its accompanying matrix provide a structured analytical basis for comparative analysis and the preliminary formulation of design-oriented insights for inclusive early childhood learning environments, while remaining subject to further empirical validation before application as fully operational evaluation tools.

To further clarify the interpretive use and scope of the proposed coding structure, Table 7 summarizes how the codes in Table 6 are defined, applied, and limited within the context of this study.

Table 7. Interpretive Use of the Codes in Table 6.

Component	Explanation
Code	A shorthand label for a proposed design condition (e.g., L1, A3, SL2).
Function	Identifies the primary regulatory intention of the design variable within the SIAF logic.
Analytical Use	Supports comparative reading of compatibility, conflict, and management strategies across ASD, DS, and ADHD.
Current Status	Proposed analytical construct, not an empirically validated operational indicator.
Not Yet Defined	No measurement threshold, scoring range, weighting logic, or standardized assessment protocol has yet been established.
Appropriate Use in This Study	Literature synthesis, conceptual comparison, and preliminary design interpretation.
Future Requirement	Field validation, measurable criteria, inter-rater testing, and threshold calibration.

6. Limitations and Future Research

The findings of this study are limited to a systematic review of the literature (n = 29) conducted in accordance with the PRISMA protocol, which may constrain the generalizability of the conclusions across diverse cultural and educational contexts. Furthermore, the proposed SIAF is grounded in an interpretive synthesis of evidence without direct empirical field validation. The analysis focuses on three neurodevelopmental profiles (ASD, DS, ADHD) as generalized response patterns, despite the considerable intra-group variability within each category, while the coding logic and analytical matrices remain proposed analytical structures not yet tested as quantitative evaluation tools. Accordingly, the study recommends applied and experimental research to validate the framework, develop measurable indicators, and further explore the potential for developing digital design decision-support systems. Future investigations should also expand the scope to additional neurodevelopmental profiles and contextual settings within a multidisciplinary approach. The study underscores the importance of integrating architecture, environmental psychology, neuroscience, and special education to deepen understanding of the dynamic interaction between the built environment and neuro–emotional regulation among neurodiverse children.

7. Conclusions

This study presented a systematic review and an in-depth interpretive synthesis of the architectural literature on sensory–interactive design in early childhood learning environments supporting children with ASD, DS, and ADHD. Moving beyond conventional descriptive approaches, the study reconceptualized elements of the built environment as active regulatory variables that are understood to shape sensory load, cognitive regulation, and behavioral–emotional responses within inclusive educational settings. The findings demonstrate that a single architectural element—such as lighting, color, acoustics, or spatial organization—does not produce a uniform effect; rather, it generates differentiated and sometimes conflicting responses depending on variations in sensory processing and emotional regulation across neurodevelopmental profiles. These results underscore the limitations of standardized design approaches or generalized "best practice" models and affirm that effective inclusive design does not eliminate difference, but instead manages it through deliberate and systematic regulatory strategies.

Within this context, the study developed a proposed analytical model, the SIAF, which integrates neurodevelopmental response patterns, sensory–emotional regulation mechanisms, and regulatory environmental dimensions to interpret and explain behavioral and cognitive outcomes. The framework does not position architectural design as a direct therapeutic instrument, but rather as a regulatory mediator operating through sensory gradation, spatial clarity, and controllability, thereby supporting stability and educational engagement without imposing additional cognitive burden. Furthermore, the study translated the findings of the systematic review into a structured analytical approach through a coding logic and comparative analytical matrices that systematically identify zones of compatibility and conflict across ASD, DS, and ADHD profiles. This approach provides a structured interpretive basis for understanding and comparatively assessing existing educational environments and informing evidence-based architectural decision-making in pre-design phases.

This transition from theoretical analysis to structured analytical interpretation constitutes one of the study's core contributions to advancing evidence-based inclusive design discourse. Accordingly, the study concludes that the design of inclusive early childhood learning environments should be grounded in the dynamic management of sensory–cognitive variability within a spatial system that is flexible, predictable, and regulatorily graduated, rather than structured around a single diagnostic profile or simplified notions of shared needs. According to the findings, adopting this regulatory perspective may contribute to improving the quality of educational experience and emotional regulation among neurodiverse children, while also highlighting directions for the development of evaluative instruments, digital decision-support systems, and more context-responsive and evidence-informed design approaches in future educational environments.

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