

Article

Neuroarchitecture and Learning in Children with ASD: Empirical Evidence from Therapeutic Centers in Lima

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Abstract

Growing evidence positions the built environment as an active component of the developmental experience of children with Autism Spectrum Disorder (ASD). In this population, architectural elements such as lighting, acoustics, spatial configuration, and sensory stimuli are consistently associated with learning processes; however, empirical evidence quantifying these relationships through proxy informant instruments remains scarce, particularly in Latin American urban contexts with infrastructure gaps. This study addresses that gap by examining the association between neuroarchitecture, understood as evidence-based sensory design, and learning in children with ASD attending therapeutic centers in the district of Comas, Metropolitan Lima. A quantitative, non-experimental, cross-sectional, and correlational design was adopted. The final sample comprised 98 proxy informants, family members with daily and sustained contact with children with ASD, recruited from four therapeutic centers in Comas (zones 3, 5, 6, and 8), following an instrument validation process that included a pilot test with 15 additional participants. Data were collected through a structured questionnaire of 24 Likert-scale items with five response options, organized around two variables and six dimensions. Content validity was established through expert judgment by five architecture specialists. Construct validity was assessed using Exploratory Factor Analysis (KMO = 0.744; Bartlett's sphericity test: $\chi^2 = 665.96$, $df = 276$, $p < 0.001$). Instrument reliability was confirmed through Cronbach's alpha coefficient ($\alpha = 0.844$). Given the non-normal distribution of the data across all constructs (Shapiro–Wilk, $p < 0.05$), Spearman's rho coefficient was used for inferential analysis. A positive and statistically significant association was identified between neuroarchitecture and learning ($\rho = 0.599$, $p < 0.001$). Dimensional analysis revealed a hierarchical pattern: the strongest association corresponded to cognitive processing ($\rho = 0.492$, $p < 0.001$), followed by social interaction and communication ($\rho = 0.460$, $p < 0.001$) and sensory regulation and adaptive behavior ($\rho = 0.460$, $p < 0.001$). A total of 99.0% of proxy informants perceived adequate neuroarchitectural conditions and associated adequate learning outcomes. The findings confirm that neuroarchitectural design is significantly associated with the learning of children with ASD, with cognitive processing emerging as the dimension most sensitive to spatial conditions. The evidence supports the formulation of preliminary design orientations that prioritize sensory stimuli management, spatial legibility, and programmatic differentiation of therapeutic environments, in alignment with Sustainable Development Goals (SDGs) 4 and 11.



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1. Introduction

The physical conditions of the built environment are closely linked to the cognitive, emotional, and behavioral processes of its users: environmental factors such as lighting, color, acoustics, and spatial layout are consistently associated with the sensory and cognitive experiences of those who inhabit a space [1]. This relationship is especially significant for children with Autism Spectrum Disorder (ASD), for whom each environmental stimulus may represent either a developmental opportunity or a source of sensory overload. Neuroarchitecture systematically investigates this interaction between built space design and the neurological, emotional, and cognitive processes of users, with the aim of informing design criteria tailored to the specific needs of different populations [1].

The relevance of this approach in the context of ASD is grounded in well-documented neurological evidence. Children with ASD exhibit differences in the organization and connectivity of their brain structures, particularly in the limbic and neocortical networks [2], with narrower neural minicolumns and altered cerebral connectivity that condition how the nervous system processes environmental stimuli [2,3]. These structural characteristics affect processes such as language and cognitive functioning, modulating symptom severity as a function of the environmental context in which the child develops [4]. International evidence documents that sensory design is associated with measurable functional outcomes: analysis of the Caudwell International Children's Centre in the United Kingdom reported improvements in concentration and sensory regulation in 82% of regular attendees [5]; rehabilitation spaces in China reported a 68% increase in adaptive behavior [6]; and multisensory design centers documented a reduction in sensory stress episodes in 79% of children with ASD [7]. Experiences in Argentina [8] and Mexico [9,10] confirm the relevance of these principles in Latin America. Research on digital therapeutics and technology-assisted interventions has further expanded the evidence base for ASD intervention [11,12], although the region continues to face persistent limitations in specialized infrastructure and professional training.

From a therapeutic architecture standpoint, adaptable spaces have been associated with reductions in disruptive behaviors and increases in prosocial ones in children with ASD [13], and evidence-based design provides the foundation for guiding these space-therapeutic interventions [14]. This approach aligns directly with SDG 4, which promotes inclusive and quality education for all, and with SDG 11, which advances sustainable cities through accessible infrastructure [15]. In the Peruvian context, however, national studies identify recurring challenges in acoustics, lighting, and safety in therapeutic centers for children with ASD [16], highlighting a gap between international advances and local conditions. Recent research in Metropolitan Lima has begun to address this gap by documenting positive associations between the sensory dimensions of the built environment and the functional capacities of children with ASD through proxy informants and Spearman correlations [17]. In a parallel methodological line, studies in populations with specific needs in vulnerable urban contexts of Lima have confirmed the feasibility and robustness of this correlational approach using aggregated Likert scales [18]. Nevertheless, none of these studies has examined learning as a differentiated dependent construct in therapeutic centers in Comas, nor has any incorporated cognitive processing, social interaction, and sensory regulation as independent analytical dimensions. This gap shapes the focus of the present study.

Building on this background, the central research question is: How is neuroarchitecture associated with the learning of children with ASD in therapeutic centers in the district of Comas, Lima, 2025? The general objective is to analyze this association considering the spatial, sensory, and environmental conditions of the built environment, with specific

objectives focused on cognitive processing, social interaction and communication, and sensory regulation and adaptive behavior. The general hypothesis proposes that neuroarchitecture is significantly associated with learning. This hypothesis is disaggregated into three specific ones for each learning dimension, grounded in the understanding that the spatial and sensory components of the built environment operate as active mediators of the learning processes of this population.

2. Theoretical Framework and Conceptual Model

2.1. Neuroarchitecture: Theoretical Foundations and Operational Dimensions

Neuroarchitecture examines the relationships between the built environment and the neurological, emotional, and behavioral processes of its users, with the purpose of generating design criteria that respond to the functional needs of different populations [1]. Pallasmaa establishes that spatial experience is constituted through the convergence of multiple sensory perceptions, including tactile, auditory, olfactory, and kinesthetic dimensions, which collectively give form to spatial meaning and embodied environmental understanding [19]. Building on this phenomenological foundation, Malnar and Vodvarka develop a framework in which the built environment is organized through differentiated sensory systems that can be deliberately identified, analyzed, and configured through design decisions. Each perceptual modality is thus understood as a distinct contributor to the overall user experience [20]. Complementarily, Rapoport demonstrates that spatial design conditions the possibilities for action, interaction, and behavior, operating not as a neutral container but as a stimulus system that structures how individuals inhabit and appropriate their environment [21]. This multidimensional and functional conception of space provides the theoretical basis for operationalizing neuroarchitecture through three dimensions: sensory stimuli, spatial configuration, and therapeutic environments [1,7,22–25].

Within this operational framework, each dimension translates into specific architectural properties whose influence on the comfort and cognitive processes of children with ASD has been documented in the literature. In acoustics, the relevant properties include the level of background noise, the presence of echo, and the degree of reverberation; the suggested control varies according to the level of focus required in the activity, with quieter conditions favoring sustained attention and louder or less controlled conditions interfering with comprehension and self-regulation [26]. In lighting, the relevant properties include the source and uniformity of illumination, the avoidance of flickering and harsh fluorescent sources, and the option for adjustable, indirect lighting, all of which influence visual comfort and reduce the likelihood of overstimulation [26,27]. In materiality, the relevant properties include the continuity of surfaces, the absence of abrupt tactile contrasts, and the use of non-aggressive textures, which support bodily confidence in the space and reduce avoidance responses [28]. In spatial configuration, the relevant properties include sensory zoning, the provision of escape spaces with minimal stimulation, clear compartmentalization, and graded transitions between areas of different sensory intensity, all of which support spatial legibility and anticipatory behavior [22,26]. Taken together, these properties constitute the architectural and physical criteria through which neuroarchitecture acts on the sensory experience and learning processes of children with ASD.

2.2. ASD and Its Relationship with the Built Environment

According to the American Psychiatric Association, ASD is characterized by atypical patterns of response to environmental sensory stimuli, which may present as hypersensitivity or hyposensitivity and vary in intensity across the spectrum [29]. Dunn posits

that individual differences in sensory processing determine how environmental stimuli are perceived, organized, and acted upon, with direct consequences for interaction and adaptive functioning [30]. In the context of ASD, this dynamic means that the built environment can either amplify or attenuate the child's difficulties: when it is not adapted to the child's sensory profile, perceptual overload may translate into disruptive behaviors and barriers to learning; when it is, the environment supports emotional regulation and fosters prosocial behaviors [13,27]. Mostafa has documented that stimulus regulation, spatial legibility, and structured environments are fundamental strategies for reducing sensory overload in this population [26], with continuous surfaces and non-aggressive textures contributing to improved environmental predictability and a sense of safety during movement [28].

2.3. Learning in Children with ASD: Dimensions and Spatial Mediation

Learning is functionally defined as the set of behavioral changes that result from experience and from the organism's adaptation to the regularities of its environment [31]. Vygotsky contends that cognitive processes unfold within a relational context in which the physical and social environment mediates learning and individual agency, either enabling or constraining the range of possible actions [32]. In children with ASD, this mediation is particularly consequential: sensory integration serves as the bridge between the child's capacities and the cognitive demands of learning, with direct implications for attention, communication, and adaptive behavior [33]. This interconnection reflects a broader understanding of learning that is especially relevant in therapeutic contexts for children with ASD: unlike narrower cognitive definitions, learning in this population encompasses the simultaneous development of sensory, social, and cognitive competencies as interdependent functional outcomes of therapeutic intervention [34]. From a perspective that integrates neuroscience and education, the relationship between emotions, cognition, and behavior in children with ASD confirms that these dimensions cannot be addressed in isolation, as each one constitutes a prerequisite for the others to unfold in the context of the therapeutic environment [35]. For the purposes of this study, learning is operationalized through three dimensions: cognitive processing (sustained attention, comprehension, short-term memory, and problem-solving); social interaction and communication (initiating communication, group participation, conversation, and non-verbal language use); and sensory regulation and adaptive behavior (self-regulation, tolerance to environmental changes, routine adaptation, and appropriate responses to novel situations).

2.4. Conceptual Model of the Study

The conceptual model articulates the association between neuroarchitecture and learning, assuming that the sensory configuration of the built environment is linked to the ways in which children perceive, process, and interact with their everyday space. Neuroarchitecture functions as the independent variable through its three dimensions, while learning constitutes the dependent variable through its three dimensions. As Rapoport establishes, the environment structures opportunities and constraints for action; accordingly, when the space is responsive to the child's sensory profile, the possibilities for learning are expanded [21]. Children with ASD attending therapeutic centers in Comas constitute the reference population, and the empirical hierarchization of associations across dimensions provides the primary input for formulating preliminary architectural design orientations [14,22]. Figure 1 synthesizes the conceptual model, illustrating the association between the two variables and their respective dimensions.

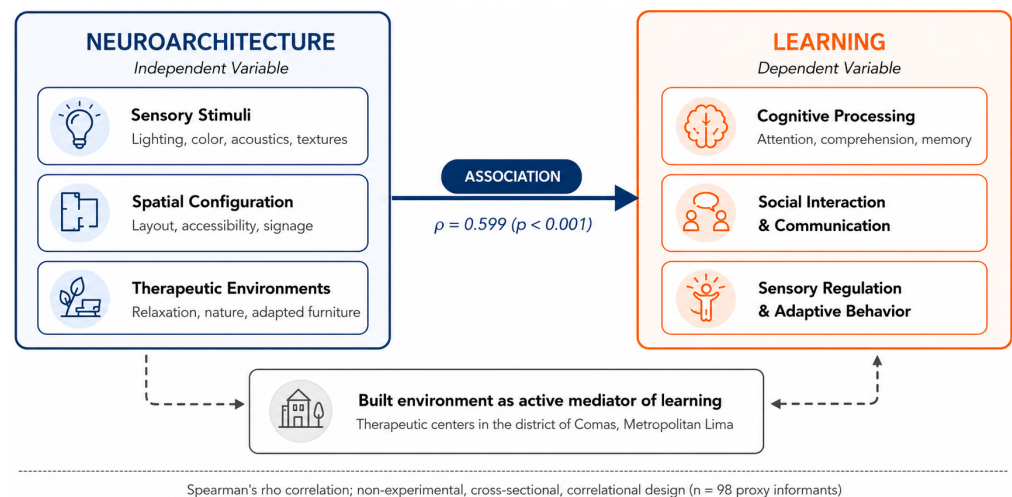


Figure 1. Conceptual model of the study. Neuroarchitecture, operationalized through three dimensions (sensory stimuli, spatial configuration, and therapeutic environments), is examined in association with learning, operationalized through three dimensions (cognitive processing, social interaction and communication, and sensory regulation and adaptive behavior). The built environment is conceived as an active mediator of learning in the therapeutic centers of the district of Comas.

3. Methods

3.1. Research Type and Design

This is a basic research study oriented toward generating theoretical knowledge about the relationship between neuroarchitecture and learning in children with ASD. A quantitative approach was adopted, focused on the collection and analysis of numerical data that allow for an objective evaluation of the association between the study variables. The design is non-experimental, given that the variables were observed in their natural context without any manipulation or control, and cross-sectional, since data were collected at a single point in time. In coherence with these elements, the scope is correlational: the study examines the association between previously defined variables without establishing causal relationships, which is consistent with the objective of translating the identified relational patterns into inputs for preliminary architectural design orientations.

3.2. Population, Sample, and Sampling

The district of Comas was selected as the study setting based on geographic, demographic, and urban criteria that make it representative of the Latin American urban contexts to which the study is projected. Located in the northern sector of Metropolitan Lima, Comas is the fourth most populated district of the province of Lima, with 520,450 inhabitants according to the 2017 National Census [36]. The district presents one of the highest demographic growth rates in the city, driven largely by internal migration, with a substantial proportion of its population concentrated in consolidated informal settlements located on the upper hillsides. This high-density urban configuration, combined with a limited supply of specialized therapeutic centers for children with ASD, makes Comas a pertinent context for examining how neuroarchitecture relates to learning under conditions of infrastructure constraint.

The reference population of the study comprised children with ASD attending four therapeutic centers located in the district of Comas, distributed across zones 3, 5, 6, and 8. These centers operate in premises adapted for therapeutic use rather than purpose-built facilities, a condition common in the district, and present limitations in specialized infrastructure such as restricted spatial dimensions, absence of dedicated sensory control systems, and reliance on pre-existing residential or commercial layouts. Given that the cognitive,

communicative, and sensory characteristics of ASD limit direct self-report, data collection was not conducted with the children themselves but through proxy informants, that is, family members with daily and sustained contact who constituted the unit of analysis of the study. This strategy is methodologically supported by research documenting its appropriateness when self-report may be affected by cognitive or functional limitations [37], and has been employed in studies on sensory architecture and functional capacities in children with ASD in Metropolitan Lima, yielding methodologically robust results [17]. The feasibility of this correlational approach using Likert scales and Spearman's rho has also been confirmed in research on sensory architecture in vulnerable urban contexts in Lima with other populations with specific needs [18].

Inclusion criteria for proxy informants were: being a direct family member of the child with ASD (parent, mother, legal guardian, or primary caregiver); maintaining daily and sustained contact with the child both at home and in the therapeutic setting; the child attending regularly at one of the four selected centers; and agreeing to participate voluntarily with informed consent. Exclusion criteria were: family members with sporadic or indirect contact with the child; questionnaires with incomplete responses; and those with a uniform response pattern across all items suggesting insufficient attention to the instrument. Applying these criteria ensured that the data reflected systematic and contextualized observations of the child's everyday performance in the therapeutic environment.

Non-probabilistic convenience sampling was employed, selecting proxy informants based on availability and direct connection to the population of interest. To support the adequacy of the sample size, statistical criteria standard in correlational studies were applied, assuming a significance level of $\alpha = 0.05$, a statistical power of 0.80, and a medium expected effect size ($r = 0.30$), in accordance with the parameters proposed by Cohen [38]. Under these assumptions, a minimum sample size of 85 participants was estimated; the final sample of 98 proxy informants exceeded this threshold, ensuring adequate statistical power for the planned inferential analyses. Prior to the definitive administration, the instrument was subjected to a pilot test with 15 additional participants not included in the final sample, with the purpose of evaluating item comprehension, response time, and the apparent coherence between the indicators and the theoretical constructs. The results confirmed that the items were comprehensible to the proxy informants, that the response time was appropriate, and that no ambiguities existed in the wording of the questions, allowing the definitive administration to proceed without substantial modifications.

3.3. Variables and Operationalization

The study variables were operationalized through their dimensions and indicators, ensuring a direct correspondence between the theoretical constructs and their empirical measurement. The independent variable, neuroarchitecture, was decomposed into three dimensions. The first, sensory stimuli, assessed perceived natural lighting, the presence of colors conducive to calm, noise control, and the appropriateness of textures and materials to the child's sensory sensitivity (items 1 to 4). The second, spatial configuration, captured perceptions about the clarity of space distribution, accessibility and ease of movement, the existence of comprehensible signage, and flexibility for different activities (items 5 to 8). The third, therapeutic environments, measured the availability of relaxation spaces, group interaction areas, contact with nature, and adapted furniture (items 9 to 12).

The dependent variable, learning, was likewise decomposed into three dimensions. Cognitive processing encompassed the child's level of sustained attention, ease of instruction comprehension, short-term memory capacity, and problem-solving in the therapeutic environment (items 13 to 16). Social interaction and communication included the ability to initiate communication with others, participation in group activities, capacity to maintain a

brief conversation, and appropriate use of non-verbal language (items 17 to 20). Sensory regulation and adaptive behavior captured the capacity for self-regulation in response to environmental stimuli, tolerance to changes in the environment, adaptation to established routines, and appropriate behaviors in novel situations (items 21 to 24). Each dimension was scored on a scale from 12 to 60 points, with classification ranges at three levels: inadequate (12 to 28), partially adequate (29 to 44), and adequate (45 to 60).

3.4. Data Collection Instrument

Following the one-to-one correspondence established between each theoretical indicator and its respective item in Section 3.3, data were collected using a structured questionnaire of 24 items formulated on a five-category Likert scale, where 1 corresponded to 'strongly disagree' and 5 to 'strongly agree,' ensuring that the instrument reflects with precision the conceptual structure of both study variables. All items were worded in a positive direction to facilitate homogeneous interpretation of responses and avoid reverse coding procedures, and were administered online through the QuestionPro platform, enabling automatic consolidation of responses. By way of illustration, within the sensory stimuli dimension, items included: 'The spaces of the therapeutic center with adequate natural lighting allow my child to carry out activities comfortably.' Within the cognitive processing dimension, a representative item was: 'The spaces of the therapeutic center support my child in maintaining sustained attention during learning activities.'

Instrument quality was evaluated on two dimensions. Content validity was established through expert judgment by five specialists with training in architecture and experience in educational and therapeutic infrastructure design, with professional experience ranging from 17 to 40 years, who evaluated the items according to criteria of clarity, relevance, and coherence with the study constructs. Construct validity was assessed using Exploratory Factor Analysis; the Kaiser–Meyer–Olkin (KMO) index reached 0.744, indicating meritorious data adequacy for factor analysis, and Bartlett's sphericity test was statistically significant ($\chi^2 = 665.96$, $df = 276$, $p < 0.001$), confirming that the latent structure of the instrument is factorable. Reliability was determined using Cronbach's alpha coefficient: the overall value was $\alpha = 0.844$, with $\alpha = 0.742$ for the neuroarchitecture variable and $\alpha = 0.754$ for learning, indicating a high level of internal consistency for both variables. This methodological decision is consistent with approaches that support the use of aggregated Likert scales to analyze associations between constructs in correlational perception studies [39,40]. It should be noted that the instrument was designed as a context-specific exploratory tool, developed for and validated within the particular characteristics of therapeutic centers in the district of Comas; its application in other urban contexts or therapeutic settings would require an independent validation process before its results could be considered transferable.

3.5. Data Analysis

Data were exported from QuestionPro into a single database and analyzed using IBM SPSS Statistics version 31.0.1.0. Prior to the inferential analysis, the normality assumption was assessed by applying the Kolmogorov–Smirnov test with Lilliefors correction and, complementarily, the Shapiro–Wilk test for a more stringent contrast. Results indicated that none of the study constructs followed a normal distribution ($p < 0.05$ in all cases), which determined the use of non-parametric statistics. Accordingly, the association between neuroarchitecture, its dimensions, and learning was examined using Spearman's rho correlation coefficient, which is appropriate for ordinal-scale variables without assuming normality. This procedure made it possible to identify relational patterns between the sensory conditions of the built environment and learning processes and, based on the

differentiated magnitude of the coefficients obtained, to establish an empirical hierarchization of the dimensions that serves as the basis for formulating preliminary architectural design orientations.

This analytical model and the resulting hierarchization were represented in Figures 1 and 2, whose visual refinement, together with the generation of the graphical abstract, was carried out with the GPT tool (Model 5.5, Version 1.2026.118), the output being reviewed and edited, with full responsibility for the content of this publication assumed.

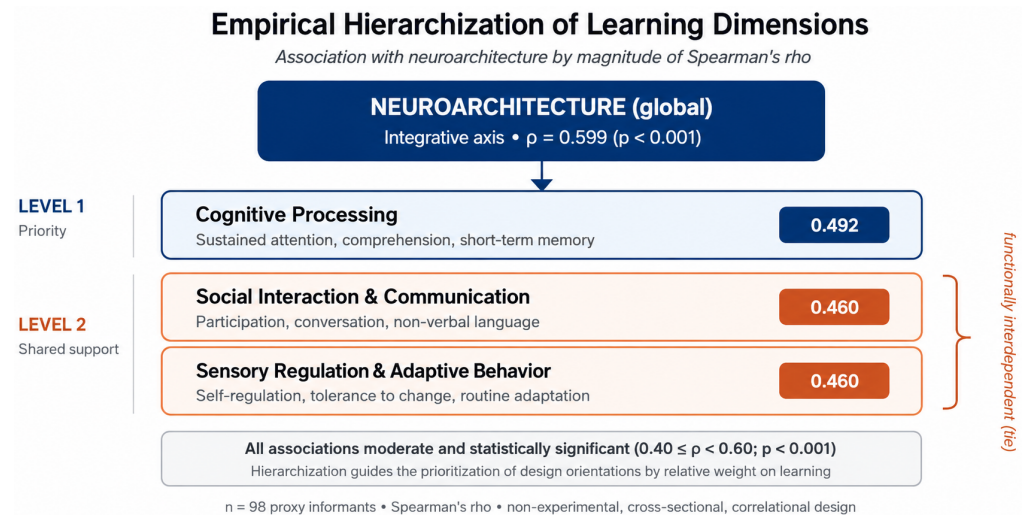


Figure 2. Empirical hierarchization of learning dimensions according to their magnitude of association with neuroarchitecture. Cognitive processing occupies the first hierarchical level as the priority dimension, while social interaction and communication and sensory regulation and adaptive behavior share the second level with identical association magnitudes, reflecting their functional interdependence. All associations are moderate and statistically significant.

3.6. Ethical Considerations

The study was conducted in accordance with the ethical principles applicable to research involving human beings. Given that the reference population comprised children with ASD, data collection was not conducted directly with them but through their primary family members and caregivers, which avoided exposing this population to self-report instruments and limited the study to the collection of perceptions about built environment conditions. Participation was voluntary, anonymous, and confidential; prior to questionnaire administration, informants received a clear explanation of the academic objectives of the study and provided their informed consent. No personally identifiable information was collected, and the data were stored in protected files with access restricted to the research team. In accordance with institutional guidelines and the non-interventional nature of the study, formal approval from an ethics committee was not required.

4. Empirical Results and Hierarchization of Sensory Design Criteria

4.1. Sample Characterization

The empirical analysis was conducted based on 98 valid responses provided by family members and primary caregivers of children with ASD acting as proxy informants. These informants were selected on account of their daily contact and sustained observation of the children's functional performance in therapeutic and home environments, which made it possible to gather information grounded in direct and recurrent experiences. The informants' responses do not represent abstract perceptions or general assessments but rather indirect records of everyday practices associated with spatial use, children's responses to environmental stimuli, and performance across the learning dimensions in

real-world contexts. Descriptive analysis revealed that 99.0% of proxy informants perceived adequate neuroarchitectural conditions in the therapeutic centers and associated adequate learning outcomes in their children, while the remaining 1.0% reported partially adequate conditions in both variables. This distribution is consistent with the profile of the centers analyzed, which operate under specialized care criteria in the district of Comas, and establishes an adequate empirical basis for examining the associative patterns between the study variables.

4.2. Correlation Analysis Between Neuroarchitecture and Learning

Prior to the inferential analysis, the normality assumption of the distributions was assessed using the Shapiro–Wilk test. Results indicated that none of the study constructs followed a normal distribution (neuroarchitecture: $W = 0.960$, $p = 0.004$; learning: $W = 0.951$, $p = 0.001$; cognitive processing: $W = 0.866$, $p < 0.001$; social interaction: $W = 0.893$, $p < 0.001$; sensory regulation: $W = 0.856$, $p < 0.001$). In all cases the p -value fell below the established significance level ($\alpha = 0.05$), leading to the rejection of the null hypothesis of normality and justifying the use of Spearman's rho correlation coefficient for the inferential analysis.

The non-parametric analysis showed that neuroarchitecture and learning in children with ASD were positively and significantly related ($\rho = 0.599$, $p < 0.001$, $n = 98$). In practical terms, proxy informants who perceived more favorable sensory conditions in the built environment also reported higher learning levels in the children. Because the study is non-experimental and cross-sectional, this coefficient is read as a moderate relational pattern rather than as evidence of causation. Its magnitude nonetheless establishes neuroarchitecture as a built-environment component reliably linked to learning in this setting, which justifies moving to a dimension-by-dimension examination to determine where the strongest links occur and to build the hierarchy that informs the preliminary architectural design orientations.

4.3. Hierarchization of Learning Dimensions

Dimensional analysis made it possible to establish an empirical hierarchization of learning dimensions according to the magnitude of their association with neuroarchitecture. This hierarchization was constructed based on Spearman's rho coefficients obtained for each dimension, all of which were statistically significant ($p < 0.001$), and constitutes the analytical foundation for the differentiated formulation of preliminary architectural design orientations.

Cognitive processing occupied the first hierarchical level with the highest magnitude of association ($\rho = 0.492$, $p < 0.001$). This result indicates that neuroarchitecture is the component of the built environment most consistently associated with sustained attention, instruction comprehension, short-term memory, and problem-solving in children with ASD. The greater sensitivity of cognitive processing to environmental conditions is consistent with evidence documenting that the reduction of distracting stimuli, spatial legibility, and sensory control are factors consistently associated with cognitive processes in this population [26,27]. In design terms, this dimension is positioned as the priority axis guiding decisions on sensory stimuli, spatial legibility, and distractor reduction in therapeutic centers.

Social interaction and communication and sensory regulation and adaptive behavior yielded identical coefficients ($\rho = 0.460$, $p < 0.001$ in both cases), forming a shared second hierarchical level. This tie is not a trivial result; in the context of ASD, social interaction and sensory regulation are functionally interdependent processes, insofar as the child's capacity to engage in communicative exchanges depends largely on their level of regulation in response to environmental stimuli [27,33]. The fact that the built environment

is associated with both dimensions with equal intensity suggests that neuroarchitecture mediates these two processes equivalently and simultaneously, serving as environmental support for both social participation and behavioral stabilization. For design purposes, social interaction informs the configuration of meeting spaces, group interaction zones, and stimulus gradients, while sensory regulation guides the design of therapeutic environments and acoustic and lighting control.

This empirical hierarchization is synthesized in Table 1, which consolidates the coefficients obtained, their significance, the assigned hierarchical level, and the role of each dimension in architectural design.

Table 1. Empirical hierarchization of learning dimensions as preliminary design orientations.

Analyzed Dimension	Coefficient (ρ)	Significance (p)	Hierarchy Level	Role in Architectural Design
Neuroarchitecture (global)	0.599	<0.001	Integrative axis	Integrative design axis. Defines the overall environmental performance oriented toward learning, guiding decisions on spatial organization, stimulus control, and material selection.
D1. Cognitive processing	0.492	<0.001	Priority	Priority dimension. Guides decisions on sensory stimuli, spatial legibility, and distractor reduction to support sustained attention, comprehension, and memory processes.
D2. Social interaction and communication	0.460	<0.001	Relational support	Relational support dimension. Informs the design of meeting spaces, group interaction zones, and stimulus gradients to facilitate participation and active communication.
D3. Sensory regulation and adaptive behavior	0.460	<0.001	Behavioral support	Behavioral support dimension. Informs the design of therapeutic environments, material selection, and acoustic and lighting control to support self-regulation and adaptive behavior.

Note: Hierarchization established based on the magnitude of Spearman's rho coefficient. Associations were considered moderate when $0.40 \leq \rho < 0.60$. All associations are statistically significant ($p < 0.001$, $n = 98$).

4.4. Synthesis of Empirical Findings

Taken together, the results of the correlational analysis allow for a clear empirical synthesis regarding the relative weight of neuroarchitecture and its dimensions in the learning of children with ASD within the analyzed context. The evidence obtained confirms that neuroarchitecture, considered as a global variable, exhibits a positive and significant association with learning, positioning it as the integrative axis of the analytical model and as the primary empirical reference for the formulation of preliminary architectural design orientations.

When this global result is disaggregated, cognitive processing emerges as the dimension most sensitive to the conditions of the built environment, indicating that the sensory quality of the space, its legibility, and the reduction of distractors represent the environmental factors most strongly associated with cognitive learning processes in this population. At the second hierarchical level, social interaction and communication and sensory regulation and adaptive behavior present identical association magnitudes, evidence that reinforces the understanding of both dimensions as functionally interdependent processes that the environment mediates equivalently and simultaneously. This hierarchical

configuration does not imply that the second-level dimensions are less relevant for design but rather that they guide spatial decisions of a different nature than those of the first level. Together, the three hierarchical levels identified constitute the empirical input for the following section, oriented toward translating these findings into preliminary architectural design orientations.

5. From Empirical Evidence to Preliminary Architectural Design Orientations

The preceding section established the empirical hierarchization of learning dimensions according to their magnitude of association with neuroarchitecture. Building on this hierarchization, the present section develops the analytical translation process through which the statistical results are translated into preliminary, context-sensitive design orientations, deliberately avoiding the derivation of formal solutions or closed technical specifications. This methodological decision responds to the non-experimental and correlational character of the study, whose objective is not to prescribe unique spatial configurations but to propose exploratory environmental performance orientations that, grounded in the associations identified within the specific context of Comas, may inform design decision-making in comparable urban settings.

5.1. Analytical Translation from Results to Design Orientations

The translation followed three sequential stages that connect the statistical analysis with architectural formulation. The first stage identified the statistically significant associations between neuroarchitecture and each learning dimension, at both the global and the dimensional levels, using the Spearman's rho coefficients obtained. The varying magnitude of these coefficients allowed a hierarchical ordering of the dimensions, on the assumption that higher coefficients denote components with greater relative weight in the learning of children with ASD within the studied context.

In the second stage, the coefficients were read not as causal effects but as indicators of functional relevance, that is, as empirical signals of how strongly certain sensory conditions of the built environment are consistently associated with observable learning dimensions. This reading distinguished dimensions playing an integrative role, a priority role, and complementary support roles, according to their hierarchical position and their relative contribution to the overall environmental experience. The hierarchization therefore does not express causation between space and learning, but a priority structure derived from the associative patterns observed in the specific context of the study.

In the third stage, the empirical hierarchization was turned into preliminary architectural design orientations, conceived as exploratory principles that guide spatial, sensory, and organizational decision-making. Rather than prescribing specific formal configurations or particular constructive solutions, these orientations propose environmental performance conditions associated with learning in the studied context. The analytical translation thus worked as a methodological bridge between the quantitative analysis and the field of design, keeping coherence between the empirical evidence and the derived orientations, while recognizing their context-sensitive character, especially in urban settings with specialized infrastructure limitations such as the district of Comas.

5.2. Preliminary Design Orientations Derived from the Sensory Hierarchization

Based on the empirical hierarchization presented in Table 1, four preliminary design orientations were formulated, each corresponding one-to-one with the identified hierarchical levels. This direct correspondence between table rows and orientations ensures traceability between quantitative evidence and design considerations, facilitating the integrated reading of both sections. The orientations do not constitute a rigid hierarchy of

sequential application but rather a prioritization guide that reflects the relative weight of each dimension within the analyzed environmental system.

The first orientation corresponds to neuroarchitecture as the integrative design axis ($\rho = 0.599$). The associations identified in this study suggest the relevance of conceiving the built environment as a coherent sensory system, in which spatial, material, and environmental decisions are not addressed in isolation but as an articulated whole oriented toward learning. In the context of Comas, where therapeutic centers frequently operate in adapted premises with high density of use and a consolidated urban fabric, this orientation is particularly relevant; the sensory coherence of the environment does not depend on the size or area of the space but on the consistency among its perceptual components, making it applicable even under conditions of limited infrastructure.

The second orientation corresponds to cognitive processing as the priority dimension ($\rho = 0.492$). Based on its higher magnitude of association with neuroarchitecture, this preliminary orientation points toward the deliberate management of sensory stimuli, spatial legibility, and distractor reduction as conditions that support sustained attention, instruction comprehension, and memory processes in children with ASD. In dense urban environments such as the district of Comas, where external noise, lack of lighting control, and high space occupancy are associated with conditions of overstimulation, this orientation signals the priority of designing environments with active sensory control conducive to supporting the child's cognitive capacity during therapeutic sessions.

The third orientation corresponds to social interaction and communication as the relational support dimension ($\rho = 0.460$). This preliminary orientation suggests the configuration of meeting spaces, group interaction zones, and stimulus gradients that facilitate participation and active communication without imposing excessive sensory demands. In the context of the therapeutic centers in Comas, characterized by spaces of reduced dimensions and high simultaneous occupancy, this orientation reinforces the need for clear functional differentiation between individual and collective activity zones, with progressive perceptual transitions that sustain the child's disposition toward social exchange.

The fourth orientation corresponds to sensory regulation and adaptive behavior as the behavioral support dimension ($\rho = 0.460$). In coherence with its equal magnitude of association relative to the previous orientation, this preliminary orientation points toward the design of therapeutic environments, material selection, and acoustic and lighting control as conditions that support self-regulation, tolerance to change, and adaptive behavior. Given that social interaction and sensory regulation are functionally interdependent processes in children with ASD, both orientations must be addressed in a complementary manner in design; an environment that adequately manages sensory stimuli is associated with more favorable conditions for the child to sustain social interaction, and vice versa.

Taken together, these four preliminary orientations constitute an exploratory reference framework, grounded in the specific context of this study, that translates the empirical hierarchization into context-sensitive design considerations for architectural decision-making in therapeutic centers with similar socio-spatial characteristics. The relevance of each orientation is not understood as exclusive or exhaustive but as part of an integrated system in which the sensory dimensions of the environment operate in a complementary manner. In this sense, the hierarchization is not interpreted as a rigid scale of absolute priorities but rather as a guide for orienting design decisions according to their relative impact on learning, particularly in urban contexts such as Comas where resource constraints require prioritizing interventions with the greatest potential impact on the learning of children with ASD.

6. Preliminary Design Considerations for Therapeutic Centers in High-Density Urban Contexts

The preliminary orientations formulated in the previous section establish the environmental performance considerations derived from the empirical hierarchization. The present section takes one step further by developing the concrete design considerations that follow from those orientations, organized around the three learning dimensions identified in the study. These considerations do not constitute formal solutions or closed technical specifications but rather preliminary, context-sensitive design orientations derived from the associations observed in this study, particularly relevant for high-density urban contexts with characteristics comparable to those of the district of Comas, and subject to further validation before being applied in other settings.

6.1. Spatial Organization and Cognitive Processing

The design considerations for spatial organization derive primarily from the integrative orientation of neuroarchitecture as a system and from the priority orientation associated with cognitive processing ($\rho = 0.492$), which occupied the first hierarchical level in the analysis. The fact that this dimension presents the greatest magnitude of association with the built environment indicates that the way space is organized—namely the arrangement of environments, the clarity of circulation paths, and the coherence among functional zones—constitutes the architectural component with the greatest relative weight on the sustained attention, instruction comprehension, and short-term memory of children with ASD.

In design terms, this consideration points toward structuring therapeutic centers through clear and comprehensible spatial sequences that facilitate activity anticipation and reduce environmental uncertainty. The organization should favor logical circulation paths, consistent functional relationships among environments, and progressive transitions between different levels of stimulation, contributing to a stable and predictable spatial experience for children with ASD. In coherence with evidence documenting that the reduction of distracting stimuli favors cognitive processes in this population [26,27], the arrangement of environments should avoid ambiguous or excessively complex configurations that increase the cognitive load associated with orientation and decision-making.

In the specific context of Comas, where therapeutic centers operate in high-density urban fabrics and in premises not originally conceived for therapeutic use, this consideration takes on an additional practical dimension: spatial legibility and functional coherence do not depend on the size of the space but on the consistency among its organizational components. A well-defined layout, with recognizable spatial references and differentiated functional zones, can generate the cognitive conditions necessary for learning even in spaces of reduced dimensions, making this consideration one of the most accessible and highest-impact interventions available in contexts of limited infrastructure.

6.2. Stimulus Management and Social Interaction

The design considerations for sensory stimulus management derive from the relational support orientation associated with social interaction and communication ($\rho = 0.460$) and are closely articulated with the conditions of the previous dimension. Environmental sensory stimuli, including lighting, acoustics, and chromaticity, do not operate as isolated factors but as an integrated system that influences the disposition of children with ASD to participate in communicative exchanges and group activities. In this sense, the deliberate management of stimuli constitutes a prerequisite for the space to function as a mediator of social interaction.

This consideration points toward designing sensory gradients that accompany the progression of activities, reducing abrupt contrasts that may generate overload, disorienta-

tion, or avoidance behaviors in children with ASD [30,33]. The management of perceptual density should be oriented toward sustaining situations of functional social participation without imposing sensory demands that hinder communication or the child's permanence in shared spaces. To this end, group interaction spaces require clear functional differentiation from individual activity zones, with progressive perceptual transitions that sustain the child's disposition toward exchange without requiring abrupt sensory adaptation.

In the context of Comas, the high density of simultaneous space use, proximity to the exterior urban environment, and noise characteristic of consolidated residential areas generate conditions of overstimulation that can directly interfere with the social interaction of children with ASD. This reality reinforces the relevance of this consideration: acoustic control through absorptive materials, regulation of artificial lighting, and the selection of neutral chromatic palettes are relatively low-cost interventions that have been associated with improvements in the sensory conditions of the environment and, with broader possibilities for active interaction and communication during therapeutic sessions.

6.3. *Environmental Configuration and Sensory Regulation*

The design considerations for the configuration of therapeutic environments derive from the behavioral support orientation associated with sensory regulation and adaptive behavior ($\rho = 0.460$) and represent the most specifically therapeutic dimension of design. In coherence with what was noted in the previous section, sensory regulation and social interaction are functionally interdependent processes in children with ASD; an environment associated with self-regulation also tends to be associated with the child's capacity to sustain social interaction, and environments linked to social interaction are similarly linked to behavioral regulation processes [27,33]. Therefore, the considerations in this subsection should be read in continuity with those of the previous one, as two sides of the same environmental system.

From a design perspective, this consideration points toward configuring therapeutic environments that offer perceptually stable, legible, and predictable conditions, which have been associated with children with ASD being better able to anticipate how the space functions and regulate their interaction with it. The selection of materials with appropriate textures, the design of continuous surfaces, and the avoidance of abrupt tactile contrasts contribute to reinforcing the child's bodily confidence in the space and to reducing avoidance or overload responses [28,41]. Complementarily, the organization of consistent spatial routines, with activity sequences associated with clearly differentiated zones, supports adaptation to environmental changes and strengthens adaptive behavior repertoires.

For the therapeutic centers in the district of Comas, where the dense urban fabric and disordered growth of the immediate surroundings generate conditions of sensory unpredictability that filter into interior spaces, this consideration takes on particular relevance. The internal environmental configuration can operate as an active counterbalance to the variability of the exterior context: spaces with selected materials, controlled lighting, clear zoning, and stable spatial routines offer children with ASD a predictable environmental framework that supports self-regulation and adaptive behavior, regardless of the conditions of the surrounding urban environment. Taken together, the three considerations of this section constitute an integrated system of design decisions that translates the empirical hierarchization into spatial, sensory, and environmental conditions oriented toward supporting the learning of children with ASD in urban contexts with specialized infrastructure limitations.

7. Discussion

7.1. Interpretation of Findings: The Built Environment as a Mediator of Learning

The results confirm that neuroarchitecture is positively and statistically significantly associated with the learning of children with ASD in the analyzed therapeutic centers ($\rho = 0.599, p < 0.001$), indicating that the built environment does not operate as a neutral container but as an active mediator of learning processes. This finding is consistent with the central premise of neuroarchitecture: the sensory and spatial conditions of the environment are closely associated with how users perceive, process, and interact with their everyday space [1]. The moderate magnitude of the coefficient, interpreted without assuming causality, suggests that learning in this population is a multidetermined phenomenon in which the built environment constitutes a relevant but not exclusive component.

This hierarchical pattern has a theoretically coherent reading; in children with ASD, the capacity to attend, comprehend, and retain information during therapeutic sessions depends critically on the sensory conditions of the environment, given that perceptual overload interferes directly with cognitive processes before affecting relational processes [27,30]. The tie between D2 and D3 reinforces the understanding of social interaction and sensory regulation as interdependent processes that the environment mediates simultaneously and equivalently [33]. Figure 2 summarizes this empirical hierarchization, presenting the dimensions ordered by their magnitude of association with neuroarchitecture.

7.2. Theoretical Discussion: Coherence with the Foundations of Neuroarchitecture

The findings are consistent with the theoretical foundations underpinning the conceptual framework of the study. Pallasmaa establishes that spatial experience is constituted through the convergence of multisensory perceptions that orient comprehension and action in the environment [19]; the observed association between neuroarchitecture and cognitive processing empirically operationalizes this premise in a population with specific sensory characteristics. Malnar and Vodvarka propose that the sensory systems of space can be consciously designed [20]; the empirical hierarchization obtained goes one step further by suggesting that these systems do not carry equivalent weight on learning, but that the cognitive component responds with greater intensity to environmental conditions. Rapoport, in turn, argues that architectural design structures opportunities and constraints for action [21]; in this study, that structure is expressed as an empirical differentiation among learning dimensions according to their sensitivity to the built environment.

From the perspective of mediated learning, Vygotsky contends that the physical environment acts as a mediator of cognitive processes and individual agency [32], a claim that finds direct support in the primacy of cognitive processing in the obtained hierarchization. Complementarily, Dunn documents that differences in sensory processing affect how individuals perceive and respond to environmental stimuli [30], which theoretically explains why sensory regulation and social interaction are associated with equal intensity to the built environment: both depend on the child's capacity to adequately process environmental stimuli before they can be deployed as relational or behavioral processes. The theoretical contribution of the study consists in operationalizing these frameworks through quantitative evidence, moving from a general multidimensional description toward a functionally grounded hierarchical reading.

7.3. Empirical Discussion: Positioning in Relation to International and Local Evidence

The results align with international evidence documenting associations between the sensory conditions of the built environment and the functional capacities of children with ASD. Studies in the United Kingdom [5], China [6], and the Middle East [7,13] have reported observable improvements in concentration, sensory regulation, and communication

when therapeutic centers incorporate sensory design criteria tailored to the ASD profile. The present study complements this evidence by quantifying these associations through a standardized instrument with proxy informants and by hierarchizing the learning dimensions according to their relative weight, which goes beyond the homogeneous reading of multisensoriality implicit in many existing normative proposals [14,27]. While the literature has emphasized the importance of regulating sensory stimuli as a general strategy, this study shows that not all learning dimensions respond with the same intensity to the built environment, which has direct implications for the prioritization of design decisions.

In the Peruvian context, the study is part of an emerging line of research that empirically examines the relationship between sensory architecture and functional capacities in children with ASD in Metropolitan Lima. Prior research in this line has documented positive and significant associations between the sensory dimensions of the built environment and the autonomy of this population through the use of proxy informants and Spearman's rho coefficients [17]. The present study extends this evidence by incorporating learning as a differentiated dependent construct, disaggregated into cognitive processing, social interaction and communication, and sensory regulation and adaptive behavior, thereby providing a more granular reading of how the built environment is associated with different developmental processes in children with ASD in vulnerable urban contexts in Lima. Together, both studies constitute a local empirical foundation that can guide the design of therapeutic centers with specific and prioritized orientations according to the population and context.

7.4. Study Contribution and Relevance for Vulnerable Urban Contexts

The main contribution of the study lies in the systematic articulation between quantitative evidence and preliminary architectural design orientations within an urban context characterized by specialized infrastructure limitations, offering architects, public managers, and therapeutic teams a context-sensitive reference framework for prioritizing design decisions where resources are limited and interventions must respond precisely to the functional needs of children with ASD. From a methodological standpoint, the study demonstrates the feasibility of operationalizing architectural perceptions through proxy informants with Likert scales and Spearman's rho, consolidating a replicable approach for future research in the same line and in populations with similar characteristics. In alignment with SDG 4 and SDG 11, the findings contribute to strengthening the evidence base that guides the development of more inclusive, accessible, and functionally appropriate therapeutic environments for children with ASD in Latin American urban contexts.

8. Limitations and Future Research

The non-experimental, cross-sectional, and correlational design adopted in this study made it possible to identify associative patterns between neuroarchitecture and the learning of children with ASD under real-world conditions, without intervention on the environment or manipulation of variables. However, this design delimits the inferential scope of the results in two respects: it restricts the interpretation to associative patterns without establishing causal relationships between the built environment and learning, and by capturing data at a single point in time, it leaves open how these associations evolve across the child's development. Future research could strengthen this empirical foundation through longitudinal designs that examine the trajectory of the identified associations across different developmental stages of children with ASD in therapeutic settings.

The use of proxy informants introduces a perceptual mediation inherent to the design: the data reflect the family member's observation of the child's performance, not the child's direct experience of the environment. Although this strategy is methodologically

justified given the cognitive, communicative, and sensory profile of ASD [37], and has demonstrated its robustness in prior studies of the same research line in Lima [17], this perceptual mediation should be considered when interpreting the results. This consideration extends to the possibility of respondent bias: proxy informants may tend toward socially desirable responses, reporting environmental and learning conditions more favorably than objective assessment would confirm, a tendency that could partially account for the high proportion of adequate ratings observed across both variables. A related interpretive boundary concerns the learning dimensions themselves, which were assessed exclusively through proxy informant reports and therefore reflect caregiver perceptions of the child's functional performance rather than direct evaluations through standardized developmental instruments. Complementarily, the instrument captures perceptions about environmental conditions without incorporating objective measurements of environmental variables such as illuminance levels, acoustic intensity, or metric dimensions of spaces. Future research could enrich the analysis by triangulating proxy informant reports with direct systematic observation and objective measurements of the built environment, broadening the understanding of the relationship between neuroarchitecture and learning from a multimethod perspective.

The non-probabilistic convenience sampling in four therapeutic centers in the district of Comas delimits the contextual validity of the results. The empirical hierarchization obtained is valid within the analyzed context and coherent with its specific socio-spatial conditions, but cannot be statistically generalized to other urban contexts or to other therapeutic care models for children with ASD. The consolidated high-density urban fabric of Comas, the operation of therapeutic centers in adapted rather than purpose-built premises, and the particular socioeconomic profile of the district together constitute contextual conditions that shape the observed associations in ways specific to this setting, reinforcing the need for caution when reading these findings beyond the boundaries of the study. This delimitation strengthens the contextual relevance of the study and, at the same time, projects a highly relevant comparative research line: future studies could replicate the model in other districts of Metropolitan Lima or in Latin American contexts with comparable socio-spatial characteristics, analyzing the stability of the identified hierarchization in the face of variations in infrastructure type, socioeconomic context, and therapeutic care modality.

Finally, the correlational nature of the study establishes the empirical foundation for understanding the association between neuroarchitecture and learning, but does not allow for determining the extent to which a specific modification of the environment would produce measurable changes in the learning dimensions identified as priority. This limit constitutes, at the same time, the natural starting point for more complex applied research; future studies could evolve toward controlled architectural intervention designs or quasi-experimental approaches, in which specific sensory or spatial adjustments are directly evaluated for their association with cognitive processing, social interaction, and sensory regulation in children with ASD. Such designs would strengthen the link between empirical research, architectural practice, and the assessment of functional outcomes.

9. Conclusions

The results of the study confirm that neuroarchitecture is positively and statistically significantly associated with the learning of children with ASD in the therapeutic centers of the district of Comas ($\rho = 0.599$, $p < 0.001$), providing quantitative evidence that the built environment does not operate as a neutral container but as an active mediator of learning processes. This association presents a differentiated structure according to the learning dimension considered, which goes beyond the homogeneous reading of multisensoriality implicit in prior normative approaches and reaffirms the relevance of approaching the

design of the therapeutic environment from a context-sensitive, empirically grounded hierarchical logic.

When the analysis is disaggregated, cognitive processing emerges as the dimension most sensitive to the built environment ($\rho = 0.492$, $p < 0.001$), positioning it as the highest-priority design orientation and confirming that the spatial and sensory conditions of the environment are most strongly associated with sustained attention, comprehension, and memory in children with ASD. Social interaction and communication and sensory regulation and adaptive behavior presented identical association magnitudes ($\rho = 0.460$, $p < 0.001$ in both cases), demonstrating that the built environment mediates these two processes equivalently and simultaneously, which is consistent with their functional interdependence in the context of ASD. This empirical hierarchization, synthesized in Table 1, provides an empirically grounded reference for prioritizing architectural design decisions according to their differentiated association with learning.

From a methodological standpoint, the study confirms the feasibility of the quantitative approach with proxy informants, Likert scales, and Spearman's rho for empirically examining the relationship between neuroarchitecture and learning in populations with ASD, consolidating a replicable procedure for future research in the same line. From an applied standpoint, the preliminary design orientations derived from the empirical hierarchization offer architects, therapeutic teams, and public managers a context-sensitive reference for the development of more inclusive, sensorially adequate, and functionally pertinent therapeutic centers in urban contexts with specialized infrastructure limitations, in alignment with SDG 4 and SDG 11.

Beyond its empirical and methodological contributions, the study carries specific implications for the urban context in which it is situated. In high-density Latin American districts such as Comas, where therapeutic centers frequently operate in adapted premises under conditions of infrastructure constraint, the findings indicate that the sensory coherence of the environment depends less on the size or technical sophistication of the space than on the deliberate organization of its perceptual components. This makes context-sensitive neuroarchitectural orientations particularly relevant for resource-limited urban settings, where targeted and low-cost interventions can support learning without requiring large-scale construction. In this sense, the study contributes directly to SDG 4 by guiding the design of therapeutic environments that support inclusive and equitable learning for children with ASD, and to SDG 11 by advancing more inclusive, safe, and sustainable urban infrastructure in consolidated and underserved districts. The articulation between neuroarchitecture and learning thus extends beyond the architectural scale to engage with broader agendas of educational inclusion and sustainable urban development in Latin America.

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