

Article

Development of the Integrated Classroom Index (ICI): A Multi-Criteria Assessment of School Classrooms

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Abstract

The physical learning environment shapes students' well-being, health, and learning, yet its assessment remains fragmented. Existing tools focus on isolated dimensions, particularly indoor environmental quality, and rarely document transparently how design factors are weighted or how performance thresholds are derived. This study develops the Integrated Classroom Index (ICI), an original multi-criteria index integrating three design principles: personalization, environmental comfort, and stimulus. Following a sequential mixed-methods design, a literature review defined 12 design parameters and 39 indicators, whose content was validated by 42 interdisciplinary experts through a Kappa concordance analysis. A specialized subgroup of 18 experts then assigned the weights using the Analytic Hierarchy Process (AHP). Each principle is standardized to a 0 to 1 range and combined through local and principle weights, classifying classrooms as excellent, adequate, sufficient, insufficient, or poor, with guardrails that prevent trade-offs between critical dimensions. The retained parameters reached Good to Perfect agreement (Kappa up to 1.00), the AHP was fully consistent (consistency ratio = 0.083), and the principle weights were 0.59 for personalization, 0.32 for environmental comfort, and 0.09 for stimulus. The ICI offers a transparent, reproducible, and auditable framework for evaluating and improving classroom design quality.

Keywords: Integrated Classroom Index; multi-criteria assessment; school buildings; post-occupancy evaluation; building performance; indoor environmental quality; educational facilities design



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1. Introduction

In the 2022 Transforming Education Summit [1], a Statement of the Youth was made, which was based on the Agenda 2030 for Sustainable Development, in particular, Sustainable Development Goal 4: “Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all” [2]. This made a call to prioritize student mental health and well-being inside and outside the classroom, throughout schooling [2]. In this sense, moving forward with research that improves physical learning environments becomes increasingly relevant as research has indicated that these have a significant impact on teaching–learning activities that take place in schools [3–6].

Research indicates that the physical learning environment shapes students' educational experiences [7,8], affecting their motivation, well-being, and health, and consequently, their

learning process [9–16]. The influence of architecture on social power relations has been highlighted by those working in the education area [17]. It has been shown how the seemingly unimportant physical factors of the space participate in social relations [18]. Fisher called these factors “deep spatial silence,” referring to the power of the space and the influence it generates on the school’s learning and organizational structures [19]. More recently, the spatial configuration of school buildings has been associated with adolescents’ attitudes and experience of school [20] and the spatial determinants of the secondary-education classroom have been characterized in specific national contexts [21].

From the dimension of health and well-being, Minhas and Nair have recently incorporated the concept of salutogenesis, looking into the design of learning spaces that promote children’s well-being and mental and physical health. These well-designed spaces evoke position emotions and, with this, student well-being [22–24]. Salutogenic design in the “Schools for Health in Europe (SHE) network” describes six characteristics for the health and well-being of students and teaching and non-teaching staff, namely, healthy school policies, social environment, individual health skills, action competencies promoted through study plans, community engagement, school health services, and physical learning environments [25].

Previous research that has been addressed on this scale should be noted, such as that of Fisher, Sanoff [26,27], the OECD [28], and Barrett et al. [3,9,29], who made a holistic analysis, integrating different dimensions of the physical learning environments, linking different design parameters, to get to know how these parameters affect student performance.

Multiple architectural factors that affect the physical learning environment have been identified, although on evaluating or intervening, there are no indices that incorporate the different design dimensions. Although research has addressed the development of an index from different dimensions, many in isolation, this fragmentation limits complete understanding of them. As such, a multidimensional index is needed to move forward towards the continuous improvement of the education environment and, in this way, to support student and teacher well-being.

Although some research has proposed an index, this has been addressed solely from the dimensions of Indoor Environment Quality (IEQ), thermal, visual, and acoustic comfort, and air quality [30,31]. Previous research summarizes IEQ studies from a multivariable perspective, highlighting the complexity of the factors involved [32]. More recent work has advanced multicriteria approaches to classroom environmental quality: Pardo-Bosch et al. [33] and López-Carreño et al. [34] proposed decision-making frameworks and a risk index to prioritize indoor-air-quality interventions in classrooms, while Diaz et al. [35] applied a multicriteria method to optimize thermal, acoustic, and visual comfort together with air quality in classrooms. Recent field studies and reviews confirm the persistence of these challenges in schools, including a post-pandemic systematic review of classroom IEQ measurements [36], field assessments in naturally ventilated classrooms [37], and post-occupancy evaluations of school building performance [38].

Buratti et al. proposed a combined index to evaluate environmental comfort in university classrooms, considering the thermal, acoustic, and lighting conditions. Measurements of environmental factors and subjective evaluations using questionnaires were made in seven university classrooms [31]. From the results, three individual indices were proposed: A Predictive Mean Vote Index for thermos-hygrometric conditions, a Sound Index for acoustic comfort, and a Visual Index for the lighting conditions. These indices are dimensionless and standardized from 0 to 1, where values close to 1 indicate good comfort conditions, and values close to 0 indicate bad comfort conditions. The final combined index, the Combined Comfort Index (CCI), was calculated for each classroom and compared with the results of the questionnaires. However, a limitation was identified in the discrete correlation

between the CCI and the questionnaires, which suggests the need for a broader experimental campaign to verify the reliability of the new index proposed. Even though this is a significant step forward, it should be noted that it has been demonstrated that children are significantly less adaptable to the environment than adults and are more susceptible to indoor environment factors [10,39]. Along the same line, Leccese et al. [40] proposed a multicriteria method to identify and rank IEQ criticalities in existing school buildings, prioritizing environmental deficiencies to guide intervention decisions.

Regarding indicators of healthy and comfortable environments applied to schools, Tanner developed a scoring system to evaluate the design of school facilities, considering aspects such as circulation and movement, daylighting, and views [41]. He created a tool that acts as the basis to collect data on school design, referring to the contributions of different researchers such as [42–46], from the Sustainable Design and Planning Laboratory (SDPL). The design variables, identified through a prior literature review, were fine-tuned in this study through reliability analysis, making an item-to-scale analysis (Cronbach's alpha) for the 34 items chosen. This led to the inclusion of 13 items divided into three classifications. The evaluation tool included a ten-point Likert scale, where the scoring reflected the presence of a specific component in the school's physical environment. This approach allowed the assignment of ratings to schools, considering their overall score and categorizing them as superior, good, adequate, or inadequate. The methodology used in the study was based on a visit to 71 elementary schools. This research highlights the importance of including valid descriptors for each item to ensure a complete understanding of the interviewees regarding the language of patterns and the design of concepts [41].

On the other hand, Maxwell [47] and Nair [48,49] outline a methodology that allows evaluating and categorizing the effectiveness of educational spaces. Maxwell develops a rating scale for preschool classrooms to evaluate the role of the physical environment in developing the children's cognitive and social skills. The scale considers three ranges defined as excellent, adequate, and inadequate, and it also gives them a score for each range: 2, 1, and 0, respectively. In the case of Nair, the scale proposed by Maxwell is adapted. It expands upon the parameters measured, including ergonomics, flexibility of the spaces, architectural factors linked to the personalization of the physical environment, and some environmental aspects, such as lighting and acoustics. This research focuses on the classrooms as the school's vital and repetitive physical learning environment. This is the main place students are in, so they must be provided with a healthy, comfortable learning environment [50]. Thus, the physical learning environment, where the children spend considerable time, significantly impacts their physical and emotional well-being.

According to the definition by Matthews and Lippman [14,15], the physical learning environment is understood as container and contained, uniting both the built structure of the classroom and the available materials, the environmental qualities within the learning environment and its relationship with the outside, the spatial layout, the access outside, the air quality, the ventilation and temperature of the classroom, among others.

Taken together, this body of work reveals two problems that motivate the present study. From a building-science perspective, the assessment of classroom quality remains fragmented: most instruments address isolated dimensions, particularly indoor environmental quality [10,30,31], while the few that integrate several dimensions [41,47,48] do not fully document, in a reproducible way, how their design factors are weighted, how their performance thresholds are derived, and how the resulting scores are combined, which limits the reproducibility and auditability of their assessments. From the perspective of the educational process and its infrastructure, decision-makers who plan and invest in school buildings lack a comprehensive tool to prioritize interventions across all the design dimen-

sions that shape learning and well-being; current programs concentrate on energy-related indoor environmental quality and omit personalization and stimulus factors [15,51].

Addressing both problems requires a multidimensional index whose weighting and classification are explicit and reproducible. Accordingly, this study aims to develop the Integrated Classroom Index (ICI), a multi-criteria instrument that identifies, weights, and integrates the design parameters of the physical learning environment across three principles, personalization, environmental comfort, and stimulus, providing a transparent and auditable basis for evaluating and improving the quality of educational spaces.

This index's applicability extends to distinct areas, addressing the evaluation of existing environments, the design of new facilities, school planning, and the formulation of policies to intervene in school infrastructure. The goal is to provide an effective and versatile tool that contributes to the continuous improvement of the educational setting's quality, supporting initiatives at both a school design and management level. It also allows the implementation of specific measures, such as making more efficient investments to improve the quality of educational spaces.

Public Education School Infrastructure in Chile

Based on the statement of the United Nations emphasizing the need for actions that address the current education crisis, understanding that these measures will not just affect children's education today but will generate lasting benefits for future generations [1], a broader, more balanced, and effective public investment is needed in education and its infrastructure. However, the challenge consists of unifying actions that guarantee inclusion while generating a balance between well-being and environmental management, thus requiring a holistic approach.

In this context, the Chilean Ministry of Education created the social program "Infrastructure for 21st Century Public Education" to improve the infrastructure conditions of public schools in line with contemporary educational needs. This program sought to more efficiently resolve the worrying number of establishments with low-quality physical learning environment conditions, where currently around 5182 establishments need improvements [52].

Although progress has been made through an Agreement signed between the Ministry of Energy and the Public Education Directorate for energy retrofitting projects to improve the environmental quality of schools in Chile, this has mainly focused on design parameters related to indoor environment quality, with indicators that affect energy consumption. These are thermal envelope, window quality, and acoustic conditioning. However, other design parameters linked to student well-being have not been addressed. Without a doubt, these can impact their motivation apart from their well-being, and their omission needs to be addressed to comprehensively improve learning environments [15,53].

2. Methodology

This study follows a sequential mixed-methods design [54], structured in four phases that lead from the conceptual definition of the instrument to its final classification rule. In the first phase, an exhaustive literature review identifies the three design principles together with their parameters and indicators. The second phase validates the content of these parameters through a Kappa concordance analysis with an interdisciplinary expert panel. In the third phase, the parameters are weighted using the Analytic Hierarchy Process (AHP). Finally, the fourth phase constructs the index by standardizing each principle, aggregating the scores through local and principle weights, and classifying classroom performance into five categories with guardrails. Figure 1 summarizes this workflow. The challenge of this proposal is to present a multidimensional integrated vision of design principles that affect physical learning environments in Chilean classrooms, considering

the aspects studied by Barrett [9]. For this research, the fundamental design principles to consider will be the personalization of the physical space, environmental principles that impact student comfort, and the stimulus generated by different elements.

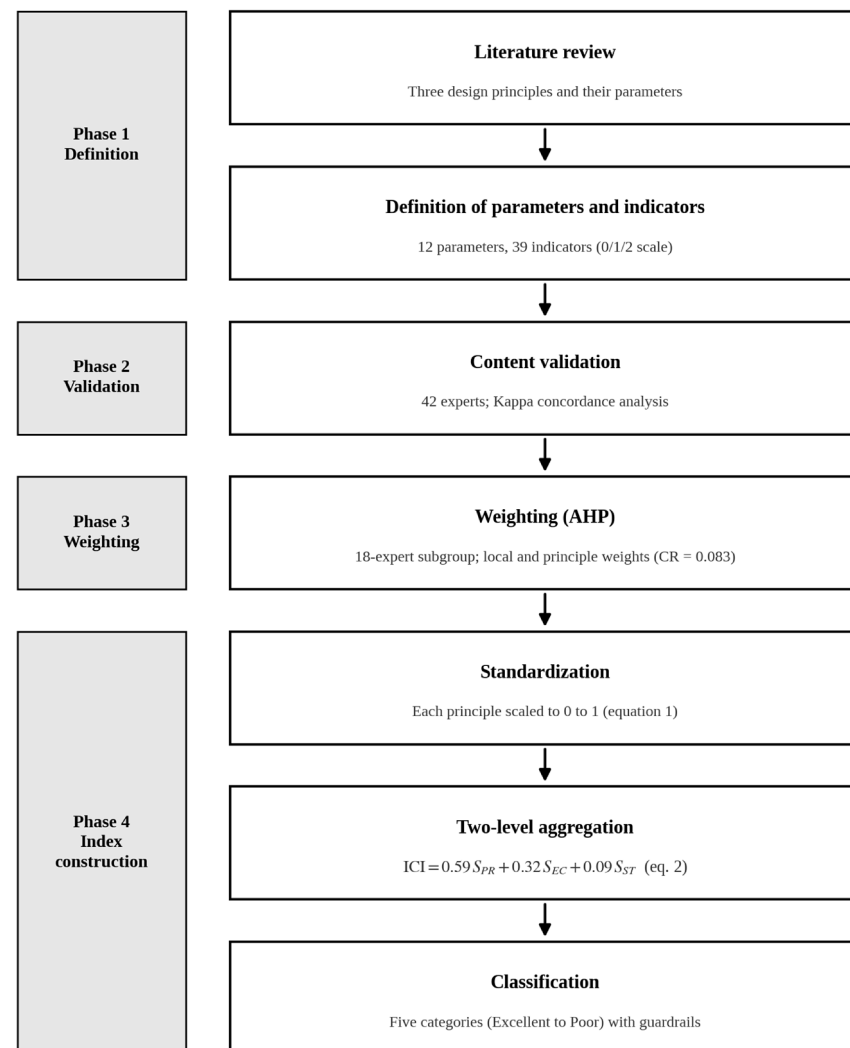


Figure 1. Research design and workflow for the development of the Integrated Classroom Index (ICI), organized into four phases: definition of parameters and indicators, content validation, weighting, and index construction.

As a personalization design principle, the parameters that allow students to feel connected to the space and experience a sense of belonging were defined, based on distinctive characteristics that contribute to the individualization of the learning experience. This principle corresponds to the dimension that Barrett terms “Individualization” [9]; within it, Spatial Appropriation is one of the constituent design parameters. Throughout this manuscript, “Personalization” designates the principle, “Individualization” is used only when referring to Barrett’s framework, and “Spatial Appropriation” denotes the specific parameter. As for the environmental design principle, this is related to indoor environment quality (IEQ). IEQ is an integrated concept that looks to provide comfortable conditions for the health and well-being of those using the space. It includes visual, acoustic, thermal comfort, and indoor air quality. Finally, the Stimulus design principle refers to the design parameters of the physical learning environment that affect the sensorial perception of the students during the learning experience [9].

Using the design principles defined in the initial phase, an exhaustive state-of-the-art exploration was made through a detailed analysis of secondary sources. This process identified the design parameters, indicators, and factors associated with the aforementioned principles, setting the basis for developing an index to evaluate and characterize educational spaces.

The second part of the search focused on peer-reviewed scientific articles published from 1980 onwards. The Web of Science (WOS), Scopus, and Google Scholar databases were used in the search, using the terms in Table 1. The search terms were organized into general terms, which define the study setting, and three categories that organize the terms related to the study factors: personalization, stimulus, and environmental comfort.

Table 1. Terms used in the search by factors considered in the study. Source: Preparation by the authors.

General	Personalization	Environmental	Stimulus
Learning environment	Classroom design	Indoor environmental quality	Color
Classroom design	Adaptability	Thermal comfort	Visual diversity
Learning impact	Variability	Acoustic design	Biophilia
Educational facilities	Appropriation	Post-occupancy evaluation	Outdoor learning
Primary schools	Connection	School building assessment	Well-being
Physical characteristics	Flexibility of learning Space	Environmental factors	--
Educational Environment	Spatial arrangement	Daylighting	--
Educational Facilities Design	Classroom furniture	Air quality	--
Elementary-Secondary Education	--	--	--
Physical learning spaces	--	--	--
Design patterns in schools	--	--	--
Learning spaces design	--	--	--
Indicators	--	--	--

The design parameters were defined using an exhaustive literature review process, divided into two fundamental stages. Research that has made specific analysis methodologies for learning environments was examined. The selection was based on the relevance and amplitude of the evaluation made in said environments, considering the three fundamental design principles for the design of educational spaces.

The design parameters were validated and then weighted in two sequential phases: a content-validation phase and an AHP weighting phase. In the first phase, 42 national experts with ties to the country's educational establishments evaluated each design parameter. These were active professionals or researchers in education (14 participants), psychology (15 participants), and architecture or design (13 participants), providing an interdisciplinary vision. A larger, diverse panel was sought at this stage so that the parameters would comprehensively and appropriately represent the construct across the relevant disciplines; agreement among these experts was then quantified through the Kappa concordance analysis (Table 7).

Depending on each expert's experience, they were asked to provide, through an online survey, the degree of relevance of the different design parameters defined. The parameters associated with their conceptual definition were presented for each design principle, duly scoring them between one and five, with 1 as not relevant at all and 5 as very relevant.

It was essential to verify these tools regarding their content. At this point, the evaluation made by professionals gains particular relevance, as they are the ones who must eliminate elements that lack relevance and adjust those that need to be adjusted [55]. For the quantification of the agreement between the experts, content validity was made. Its purpose was that

the elements or questions in a measurement tool must be pertinent and suitably reflect the concept that is being evaluated for a specific purpose [56], as cited in [57].

The Kappa index is used [58] to evaluate the concordance between the experts on the design parameters included in each of the three principles. The agreement between evaluators was interpreted, according to the index, as follows: a Kappa coefficient $|\kappa| \leq 0.20$ indicates poor agreement; $0.20 < |\kappa| \leq 0.40$, weak; $0.40 < |\kappa| \leq 0.60$, moderate; $0.60 < |\kappa| \leq 0.80$, good; $0.80 < |\kappa| < 1.00$, very good; and $|\kappa| = 1.00$, perfect agreement.

The third phase of the study focused on assigning weights to the identified design parameters. To improve accuracy and reduce uncertainty in the decision-making process, it was crucial to have experts highly specialized in educational spaces whose perspective is based on their recognized authority and experience in specific areas [59].

In this context, the weighting was carried out by a smaller, highly specialized subgroup of 18 experts drawn from the validation panel: local professionals well-versed in creating physical learning environments and with significant experience in school infrastructure. The selection applied key criteria: educators had to be specialists in pedagogical innovation and experienced in pedagogical-management consultancy; psychologists were prioritized for their experience in research on educational spaces, addressing aspects such as school coexistence and well-being; and architects and designers had to have experience in the architectural design of schools or be closely tied to research on physical learning environments in the country. These 18 experts were organized into three panels (Table 2), with a composition deliberately weighted toward spatial-design expertise (22% from education, 28% from psychology, and 50% from architecture-design), reflecting the spatial focus of the weighting task. A smaller, highly specialized panel is appropriate for the AHP, which relies on structured pairwise comparisons and prioritizes depth of expertise and the consistency of the judgments (consistency ratio = $0.083 < 0.1$; Table 10) rather than sample size.

Table 2. Organization of panels, number of experts by area. Source: Preparation by the authors.

Group	Education	Psychology	Architecture-Design
1	2	1	2
2	1	2	3
3	1	2	4

The Analytical Hierarchy Process (AHP) method developed by Thomas L. Saaty, recognized for its effectiveness in addressing complex problems with multiple criteria, was applied. This process generated a hierarchy of priorities that reflects global preferences, which is fundamental for informed decision-making [59]. This process determined the weights in percentages from 0 to 100% and assigned them to each design principle and parameter. These had been previously defined in the initial literature review and validated conceptually by the experts.

The decision was made to hold the panel in groups of three, which addressed two analysis levels. The first, at a global level, evaluated the “Personalization,” “Environmental,” and “Stimulus” design principles. The second level of analysis focused on the design parameters related to each principle (see Table 3). Each group was led by a researcher who transferred results to a spreadsheet, presented the design principles and parameters, and verified the consistency of the scores assigned in the peer-to-peer comparisons.

First, the scores for the design principles were defined to establish priorities in the weighting of the variables. Then, the design parameters were evaluated and scored considering the discussions with experts and the building of hierarchies. During this process, a peer-to-peer comparison was made of the variables, and their relative importance was

debated. These comparisons were scored on a specific scale, which allows the importance level of each variable to be determined compared to the rest.

Table 3. Peer-to-peer comparison of the design parameters related to each design principle. Source: Preparation by the authors.

Global	Personalization	Environmental	Stimulus
Local	Cultural Belonging	Thermal	Connection with nature
	Spatial Appropriation	Acoustic	Visual diversity
	Spatial Flexibility	Lighting	Integration of colors
	Ergonomics	Air quality	

In this process, peer-to-peer comparison of the variables took place, and their relative importance was debated. These comparisons resulted in scores on Saaty's specific scale, which, through peer-to-peer comparison, allowed the level of importance of each variable to be determined compared to the rest. A scale of 1 to 9 was used to score the preferences of the two elements being compared. Pairwise comparisons were made on Saaty's fundamental 1–9 scale [60], where 1 denotes equal importance of the two elements, 3 moderate importance, 5 strong importance, 7 very strong importance, and 9 extreme importance of one element over the other, while the even values 2, 4, 6, and 8 represent intermediate judgments between these levels.

The results of these comparisons were consolidated using matrix operations, thus generating a final score for each variable in each group. Next, the global and local weights were averaged to obtain a final weight that reflects each variable's relevant importance in the design's general context.

A consistency analysis was run to verify the reliability and coherence of the decisions made [60]. This process evaluated the stability and robustness of the weights obtained, ensuring that the decisions based on the AHP methodology were sound and consistent through the different phases of the study.

After weights were given to the design parameters, a matrix was developed that included the design parameters and their indicators for each design principle. Initially, 47 indicators were identified (see Appendix A), although, after an exhaustive revision of the evaluation criteria and standards, 40 indicators were chosen; the concordance analysis subsequently led to excluding one (visual diversity), yielding 39 indicators in the final instrument. Those that could be evaluated and categorized by characterizing education spaces were included.

A scoring system with three ranges, classified with a scale of 0, 1, and 2 (see Table 4), was suggested [61]. Depending on the indicator used to measure the design parameter, a factor with three compliance levels was defined [47–49,61]. The parameters, indicators, and factors are detailed in Table 6 in Section 3.

Table 4. Architectural factors categorization scale. Source: Reproduced from [61].

Category	Score	Level of Compliance
Effective	2	Fully complies with requirements
Adequate	1	Complies with the minimum required
Inadequate	0	Does not comply or apply with what is required

It was assumed that the scores obtained for each indicator of the design parameters were additive [24,41,47], which allowed a compliance score for each design principle to be obtained considering the evaluation of each parameter.

A maximum score for each design parameter is obtained on efficiently complying with each indicator (see Table 5 and Appendix B). The corresponding variations will be generated using these values depending on their adequate or inadequate integration.

Table 5. Maximum possible scores to be obtained. Source: Preparation by the Authors.

Personalization	Score	Environmental	Score	Stimulus	Score
Spatial Appropriation	6	Lighting	10	Connection with nature	8
Spatial flexibility	12	Thermal	10	Color Integration	4
Cultural Belonging	4	Acoustics	10		
Privacy	2	Air Quality	10		
Furniture	2				
$S_{\max P}$	26	$S_{\max E}$	40	$S_{\max I}$	12

To provide a quantitative and weighted evaluation of the different design principles, a method was implemented that combines the weights assigned to the specific design parameters within each design principle. This approach provides a comprehensive vision, considering the relevance of each design parameter and its scoring compared to the score obtained in each criterion.

For each design principle, a standardized score S_{DP} in the 0–1 range was obtained as the local-weighted mean of the compliance ratios of its parameters, using the local AHP weights (w_p). The standardized scores of the three principles (S_{PR} , S_{EC} , and S_{ST}) were then combined with the principle weights ($w_{PR} = 0.59$, $w_{EC} = 0.32$, and $w_{ST} = 0.09$) to obtain the Integrated Classroom Index (ICI), as detailed in Section 3.4. This two-level weighting scheme keeps every principle on a common 0–1 scale and prevents any single criterion from dominating because of differences in the number of indicators.

A classification scale was developed by building on the performance scale of Tanner [41], later used by Maxwell [47] and adapted by Minhas & Nair [24] and Nair [49]. To place the category boundaries in a principled, weight-consistent way, a theoretical anchor model was first constructed, comprising the $3^3 = 27$ canonical combinations in which each design principle (DP) adopts one of three states defined on its raw parameter score: HIGH (the maximum raw score achievable by the DP), MED (50% of that maximum), and LOW (0, no achievement). Computing the ICI over these canonical states (Figure 2) spans the decision space in a controlled manner and yields the candidate cut-off points between performance levels.

	COMBINATIONS																										
DESIGN PRINCIPLE & AHPw	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
PR w=0.59	H	H	H	H	H	H	M	H	M	H	M	H	M	M	M	L	M	L	M	L	M	L	L	L	L	L	L
EC w=0.32	H	H	H	M	M	M	H	L	H	L	H	L	M	M	M	H	L	H	L	H	L	M	M	M	L	L	L
ST w=0.09	H	M	L	H	M	L	H	H	M	M	L	L	H	M	L	H	H	M	M	L	L	H	M	L	H	M	L
ICI	1.00	0.96	0.91	0.84	0.80	0.75	0.71	0.68	0.66	0.64	0.62	0.59	0.55	0.50	0.46	0.41	0.39	0.37	0.34	0.32	0.30	0.25	0.21	0.16	0.09	0.05	0.00
CLASSIFICATION	EXCELLENT ICI ≥ 0.90			ADEQUATE 0.70 ≤ ICI < 0.90				SUFFICIENT 0.45 ≤ ICI < 0.70								INSUFFICIENT 0.25 ≤ ICI < 0.45						POOR ICI < 0.25					
	H	HIGH		M	MEDIUM			L	LOW			ICI = 0.59(S _{PR}) + 0.32(S _{EC}) + 0.09(S _{ST})															

Figure 2. Theoretical anchor model: mapping of the $3^3 = 27$ canonical combinations to the five ICI performance bands, ordered by descending ICI.

The resulting five-level scale: excellent, adequate, sufficient, insufficient, and poor, preserves the hierarchical, incremental logic of established post-occupancy performance scales and remains consistent with their threshold conventions: its anchor points align with the high-performance and acceptability cut-offs of Tanner [41] and Nair [24,49] (Figure 3). The empirical application and validation of the ICI against real classrooms is beyond the scope of the present methodological paper and is addressed in future work.

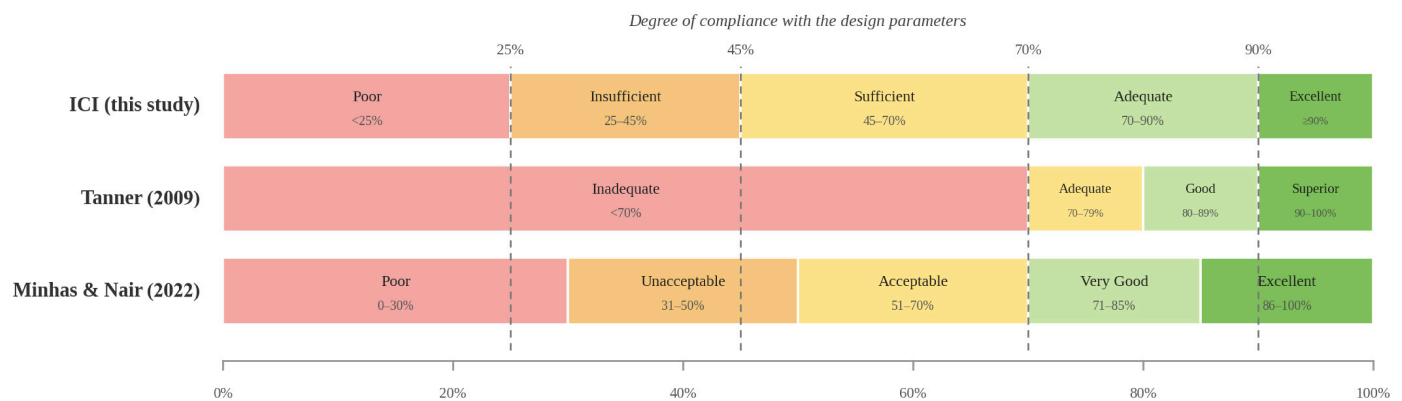


Figure 3. Alignment of the ICI five-level classification with established post-occupancy rating scales, sharing their 70% and $\geq 90\%$ anchor points while adding finer resolution in the lower range. Percentages denote the degree of compliance with the design parameters. Tanner (2009) [41], Minhas & Nair (2022) [24].

3. Results

3.1. Design Parameters Applicable to Educational Spaces

Regarding physical learning environments, Sanoff focuses on design parameters such as indoor environmental quality, aesthetics, and the use and organization of space (including classroom density indicators, flexibility of use, and furniture) [27]. Meanwhile, Fisher incorporates more aesthetic or cosmetic design parameters like color or visual diversity [26]. This also includes the diversity and variety of the environment and the learning zones from the socio-spatial dimension [18,26]. The Learning Environments Evaluation Programme (LEEP) of the OECD, humidity, lighting (natural and artificial), and acoustics. In addition, it includes design parameters linked to aesthetics, color, and design of the school furniture. The spatial dimension addresses the design parameters, spatial adaptability of the classroom, spatial and furniture flexibility, pedagogical flexibility, and inclusive design [28]. From an integrated approach, three dimensions stand out, the first referring to “Naturalness,” which covers environmental design parameters that affect student comfort and well-being, such as light, temperature, air quality, sound, and connection with nature. The second dimension is “Individualization,” which includes design parameters that allow students to personalize their space, considering ownership, flexibility, and connections with other areas of the establishment. The third and final dimension is the “Appropriate level of Stimulus,” which provides a sensorial enriching environment with the design parameters of color and visual diversity [9]. On the other hand, Nair includes different design parameters such as the personalization of the spaces, intimacy, places for playing and social interactions, learning areas, and flexibility of the space, among others [24,48]. This allowed identifying multiple and diverse design parameters to include in the design of educational spaces.

Based on the literature review, an initial matrix is proposed, which includes 12 design parameters and 47 indicators (see Appendix A). This is adjusted and reduced to 39 indicators in the final instrument (see Table 6).

For the personalization design principle, the importance of specific aspects related to the adaptability of the space stands out. Five significant design parameters were identified. Spatial Appropriation, where the indicators linked to a sufficient separation between areas of activity, learning zones within the classroom, and the incorporation of flexible elements between classrooms stand out. Similarly, Spatial Flexibility within the classroom, between classrooms, and the hallway, and Cultural Belonging, referring to the school community, were identified. In addition, Spatial Privacy was identified, including areas where students can be alone. Finally, Furniture was also identified, as a key element to allow diverse pedagogical activities.

Regarding the environmental design principle, four design parameters directly affecting the indoor environment's quality were identified, following the previously validated environmental assessment block and its digital-twin (LiDAR) survey technique [62]. These parameters were carefully chosen to reflect the best practices and recommendations that promote a physical environment fit for learning. For Air quality, ventilation, air renewal patterns, and ventilation systems stand out. For Thermal, solar gains as passive strategies for internal conditioning become relevant, and so do central heating systems as support. For Acoustic, the geometry of the space, insulation, and acoustic conditioning are highlighted. Finally, for Lighting, the contribution of daylight, the description of the openings and their distribution, the integration of daylight optimization or protection devices, and complementary artificial light stand out.

For the stimulus design principle, two essential design parameters were identified. These parameters focus on elements that stimulate the cognitive and sensorial experience of the students, thus contributing to an enriching educational environment. Connection with nature highlights the view type and the relationship with natural elements or the integration of biomorphic shapes or patterns. Integration of colors stands out as a relevant aesthetic element.

Table 6. Design parameters, indicators, factors, and proposed categorization (Source: Own elaboration).

Parameters Design	Indicator	Categorization	Reference
Cultural Identity	Welcoming access to the school	2 = Has 3 or more elements to generate a welcoming access.	[18,19,41,47,48,63]
		1 = Incorporates exactly two elements.	
		0 = Incorporates one or none of the elements that generate a welcoming access.	
	Symbols of belonging	2 = The establishment's design integrates 3 or more elements characteristic of the school community that provide identity or belonging. 1 = Incorporates exactly two elements of the school community that provide identity or belonging. 0 = The design does not incorporate elements that provide identity or belonging.	[18,19,41,47,48,63]
Spatial Privacy	Restorative spaces	2 = There are more than two safe and comfortable spaces, corners, or nooks for disconnecting. 1 = There are one or two safe, comfortable spaces or corners for disconnecting. 0 = The room has no safe and comfortable space or corner for disconnecting.	[5,47,48]

Table 6. Cont.

Parameters Design	Indicator	Categorization	Reference
Spatial Appropriation	Customizable elements	2 = There are more than two customizable elements in or adjacent to the classroom.	[5,28,41,47,48,64]
		1 = There are one or two customizable elements in or adjacent to the classroom.	
		0 = There are no customizable elements in or adjacent to the classroom.	
	Presentation surface	2 = Dedicated display areas on several walls, defined in an orderly manner.	[41,47,48,65]
		1 = Display surface exists, but on walls without orderly defined areas.	
		0 = Minimal or no surface dedicated to displaying work or didactic material.	
Furniture	Exhibition of personalized or anchor works	2 = Personalized student works and/or pedagogical anchor works are exhibited in areas specifically determined for that purpose.	[18,19,41,47,48,63]
		1 = Some personalized or pedagogical anchor works are displayed, but not in clearly defined or ordered areas.	
		0 = No personalized works or pedagogical anchor works are exhibited.	
	Furniture ergonomics and scale	2 = The furniture is ergonomic (presents curvature in the legs and cavity in the back and seat) and has a correct scale for the students.	[5,28,41,47,48,64]
		1 = The furniture has the correct scale but is not entirely ergonomic.	
		0 = The furniture does not have the correct scale and is not ergonomic.	
Spatial flexibility	Net occupancy area per student (m ²)	2 = ≥ 2.5 m ² , there is ample space for students and teachers to move around without disturbing each other.	[5,18,41,47,66,67]
		1 = ≥ 2 m ² < 2.5 m ² per student, space is adequate for almost all students to work actively and move around the room.	
		0 = < 2 m ² space is limited, and it is not easy to move around.	
	Learning areas in the classroom	2 = Contemplates at least 3 learning zones for different activities.	[28,47,48,64]
		1 = The classroom has at least 2 learning zones for different activities.	
		0 = The classroom does NOT have different learning zones.	
	Furniture/equipment for flexible use (different learning modalities).	2 = Varied furniture and equipment that allow reconfiguring the use of the space.	[18,28,47,49,65]
		1 = One or two ways to reconfigure the use of the space.	
		0 = Little or no opportunity to reconfigure the space.	

Table 6. Cont.

Parameters Design	Indicator	Categorization	Reference
Spatial flexibility	Integration of flexible elements	2 = Incorporates two or more flexible elements.	[28,47,49,65]
		1 = Incorporates one flexible element.	
		0 = Does not incorporate any flexible element.	
	Learning corridors (>3 m)	2 = Wider than 3 m, with different programmatic uses.	[41,63,64,66]
		1 = Wider than 3 m, but without differentiated uses.	
		0 = Corridor only (less than 3 m).	
Lighting	A = Traditional room. B = Traditional room with meeting space. C = Traditional room with movable walls and rest space. D = Open plan, separable into rooms. E = Open plan with some continuous spaces.	2 = Linked to more than one space and/or has movable walls and rest spaces (C, D).	[63]
		1 = Linked to a meeting space, larger than a corridor (B, E).	
		0 = Not linked to any other space (A).	
	Daylight coverage	2 = Daylight coverage between 75% and 100% of the classroom area.	[64,68,69]
		1 = Daylight coverage $\geq 50\%$ <75% of the classroom area.	
		0 = Daylight coverage less than 50% of the classroom area.	
	Distribution of openings	2 = The classroom has multilateral openings.	[70–72]
		1 = The classroom has bilateral openings.	
		0 = The classroom has one-sided openings.	
	Glazing area/glazing wall area (WWR ratio)	2 = WWR > 40%.	[28,64,72]
		1 = WWR $\geq 20\%$ $\leq 40\%$.	
		0 = WWR < 20%.	
	Integration of optimization elements	2 = The classroom has some element of lighting optimization or outdoor solar protection.	[70,71]
		1 = The classroom only has a movable curtain for lighting protection.	
		0 = There is no lighting optimization and/or solar protection device.	
	Quality of the electrical lighting	2 = Energy efficient equipment (LED), uniform temperature, in good condition, and functioning.	[3,9,72–74]
		1 = Conventional equipment, uniform temperature, in good condition and working order.	
		0 = Part of the lighting equipment is missing or without maintenance.	

Table 6. Cont.

Parameters Design	Indicator	Categorization	Reference
Acoustic	Classroom height	2 = The height of the classroom is ≤ 2.4 m.	[75,76]
		1 = The height of the classroom is between $>2.4\text{--}\leq 3.5$ m.	
		0 = The height of the classroom is >3.5 m.	
	Quality of glass and window frame	2 = Laminated or asymmetric double glazing (panes of different thickness) for acoustic insulation.	[77,78]
		1 = Standard double glazing (DVH) without specific acoustic treatment.	
		0 = Single glazing, with no acoustic attenuation.	
	Glazing area/floor area (WFR)	2 = Glazing area $\leq 10\%$ /floor area WFR.	[76,79]
		1 = Glazing area $> 10\% \leq 16\%$ /floor area WFR.	
		0 = Glazing area $> 16\%$ /floor area WFR.	
Thermal	Percentage of ceiling area with absorbent material	2 = $\geq 40\%$ ceiling area with absorbent material.	[78,80]
		1 = $>20\% < 40\%$ ceiling area with absorbent material.	
		0 = $<20\%$ ceiling area with absorbent material.	
	Percentage of wall area with absorbent material	2 = In m^2 , more than 20% of the surface of the wall with absorbent material.	[78,80]
		1 = In m^2 , less than 20% of the surface of the wall with absorbent material.	
		0 = The classroom does not have absorbent material on the walls.	
Thermal	Shading control	2 = Present and appropriate to the orientation.	[9,70,71,81]
		1 = Present and works partially.	
		0 = There is no solar protection.	
	Glazing orientation (Southern Hemisphere)	2 = The classroom has a north orientation $+/- 30$ degrees.	[9,71,81,82]
		1 = The classroom has an east–west orientation.	
		0 = The classroom has a South orientation.	
Thermal	Quality of glass and window frame	2 = At least DVH without thermal bridges (PVC frame or RPT).	[64,83]
		1 = Use of DVH glazing with thermal bridges (Aluminum frame without RPT).	
		0 = Single glazing. Independent from the materiality of the frame.	

Table 6. Cont.

Parameters Design	Indicator	Categorization	Reference
Thermal	Wall insulation	2 = Has thermal insulation and is in good condition.	[70,71,77,84]
		1 = Has the original thermal insulation of the building.	
		0 = Does not have thermal insulation in walls.	
	HVAC system	2 = There is a system, and it works correctly. 1 = There is a system that does not work due to a lack of maintenance. 0 = Does not exist or has an irreversible fault.	[3,9,82]
Air Quality	m3 x student	2 = Air volume $\geq 4 \text{ m}^3/\text{student}$.	[3,9,70]
		1 = Air volume $\geq 3 < 4 \text{ m}^3/\text{student}$.	
		0 = Air volume $< 3 \text{ m}^3/\text{student}$.	
	Percentage of openings/floor area	2 = $\geq 8\%$ of openings/floor area.	[64,70,85]
		1 = $\geq 4\% < 8\%$ of openings/floor area.	
		0 = $< 4\%$ of openings/floor area.	
	Type of Natural ventilation	2 = The classroom has cross ventilation or convective ventilation.	[9,64,70,77,81]
		1 = The classroom is ventilated through one wall and two openings.	
		0 = The classroom is ventilated through one operable opening.	
Connection to Nature	Type of openings	2 = Tilt-and-turn windows.	[9,70,77,81]
		1 = Top-hung windows.	
		0 = Sliding windows.	
	Ventilation system, quality, and performance	2 = There is a system, and it works correctly.	[9,70,77,81]
		1 = There is a system that does not work due to a lack of maintenance.	
		0 = Does not exist or has an irreversible failure.	
Connection to Nature	View outside	2 = Has a view from two or more body positions.	[5,41,47,48,64,65]
		1 = Has a view from one body position.	
		0 = Classroom has no view to the outside.	
	Quality of the outdoor view (nature, distance, movement)	2 = There is a view of nature or varied natural elements/landscape at a distance that allows contemplation with few or no obstructions. 1 = Some natural elements are observed, but there are some obstructions. 0 = There are no or very few visible natural elements, sometimes obstructed by buildings.	[5,47,48,64,65]

Table 6. *Cont.*

Parameters Design	Indicator	Categorization	Reference
Connection to Nature	Natural elements in adjacent outdoor spaces.	2 = Predominance of natural elements in spaces adjacent to the classroom or playground; the door connects directly to a natural space.	[41,47,48,64,65]
		1 = Partial presence of natural elements in spaces adjacent to the classroom or playground.	
		0 = Absence or very scarce presence of natural elements adjacent to the classroom or playground.	
	Biomorphic shapes and patterns (furniture, vegetation, décor, or images of nature)	2 = There are two or more biomorphic elements in the classroom. 1 = There is exactly one biomorphic element in the classroom. 0 = There are no biomorphic elements in the classroom.	[41,47,48,64,65]
Color Integration	Chromatic intention of surfaces (walls, floor, and ceiling)	2 = Light surfaces with an identifiable chromatic intention (soft accents or a single feature wall).	[18,19,26,41,47,48,64,65]
		1 = Slight, soft color variation; neither distracting nor monotonous.	
		0 = High contrast and material clash (distracting) or no variation at all (monotony).	
	Curtain color and translucency	2 = Light colors, material with translucency. 1 = Light colors, material without translucency. 0 = Dark or absorbent colors.	[47,48,64,70]

3.2. Conceptual Validation of the Design Parameters

Kappa concordance analysis played a central role in validating the design parameters. Eleven of the twelve parameters achieved Good to Perfect agreement ($\kappa \geq 0.65$; Table 7), confirming that the experts interpreted them consistently. Visual diversity was the sole exception, with only moderate agreement ($\kappa = 0.462$) and separated from the remaining parameters by a clear margin, the next-lowest value being 0.651. This markedly lower concordance indicates that raters applied the parameter inconsistently, reflecting its more subjective and ambiguous operationalization relative to the directly measurable parameters. To preserve the replicability of the instrument, only parameters reaching at least Good agreement were retained; visual diversity was therefore excluded, reducing the set from 40 to 39 indicators in the final instrument (Table 6).

The exclusion of visual diversity narrows the Stimulus principle, which is already the least-weighted dimension and now comprises two parameters (connection with nature and color integration). Visual diversity is nonetheless a recognized attribute of stimulating learning environments; its low inter-rater agreement points to the need for a clearer, less subjective operational definition rather than to the irrelevance of the construct. Future refinements of the ICI should re-operationalize and re-validate visual diversity so that it can be re-incorporated into the Stimulus principle.

Table 7. Design parameters organized according to degree of agreement. Source: Preparation by the Authors.

Design Parameters	Kappa
Thermal	1
Air quality	1
Acoustic	0.958
Furniture	0.917
Spatial Flexibility	0.875
Lighting	0.875
Connection with nature	0.833
Cultural Belonging	0.791
Spatial Appropriation	0.702
Spatial Privacy	0.651
Integration of colors	0.651
Visual diversity	0.462

3.3. Weights of the Design Parameters

The results of the AHP analysis made by groups are presented in Table 8, where the local weights obtained for each component of the model are shown at both a group and combined model level. The local level indicates the item's relevance compared to the variable or dimension it belongs to in the structure, thus distributing 100% of the importance between the elements this dimension forms. In other words, it reflects the relative weight within its immediate context (compared to its design principle).

Table 8. Weighting by group of the parameters design and combined weight. Source: Preparation by the Authors.

Sub-Criteria	Group 1	Group 2	Group 3	Combined
Cultural belonging	47%	17%	7%	24%
Spatial Appropriation	13%	36%	51%	33%
Spatial flexibility	22%	36%	22%	27%
Furniture	5%	7%	4%	5%
Spatial privacy	13%	4%	16%	11%
Thermal	17%	36%	38%	30%
Acoustic	17%	17%	32%	22%
Lighting	17%	11%	8%	12%
Air quality	49%	36%	22%	36%
Connection with nature	81%	72%	75%	76%
Color integration	7%	8%	7%	8%

On the other hand, the global weight reflects the importance of each item in the overall model, that is, its definitive relevance in the ICI. Three weighting levels were established in the evaluation process. In the first, a weight was assigned to each design principle, reflecting its relative importance in the model. In the second, a local weight was assigned to each design parameter within its corresponding design principle. Finally, in the third level, the global weight of each design parameter over the total is obtained as the product of its principle weight and its local weight. The resulting priorities and global hierarchy are presented in Table 9.

Table 9. Weights of design principles and parameters. Source: Preparation by the Authors.

Design Principles	Design Parameters	Design Principles Weight	Combined Local Weight	Global Weight
Personalization	Spatial Appropriation	59%	33%	20%
	Spatial flexibility		27%	16%
	Cultural Belonging		24%	14%
	Spatial Privacy		11%	7%
	Furniture		5%	3%
Environmental	Air Quality	32%	36%	12%
	Thermal		30%	9%
	Acoustic		22%	7%
	Lighting		12%	4%
Stimulus	Connection with Nature	9%	90%	8%
	Color Integration		10%	1%

The AHP demonstrated a solid integration with the “Personalization” design principle, which has the highest weight at 59%. It is positioned as the preeminent aspect in the general weighting along with its corresponding design parameters. In second place are the aspects related to the “Environmental” design principle, with a significant incidence of 32%. Finally, the “Stimulus” design principle has a weight of 9%, contributing to its unique perspective on the overall analysis.

When breaking down each design principle, the case of “Stimulus” stands out, where despite having the lowest global weight, it shows its importance locally. Specifically, the design parameter related to connection with nature reaches a stand-out local weight of 76%. However, this relevance is translated into a more moderate global impact, representing just 7% in the general weighting. This finding underlines the importance of considering not just the hierarchical position of the design principles but also the specific influence of certain parameters in the overall analysis.

The consistency analysis was calculated using the relationship analysis and revealed a factor of 0.083 (see Table 10). This value, which is within acceptable limits for consistency in the context of this study, suggests sound coherence in the responses provided by the evaluators. In practical terms, this low factor indicates that the weight assigned to the different criteria or elements examined is consistent and reliable.

Table 10. Consistency analysis. Source: Preparation by the Authors.

Consistency Analysis			
N (Order of the Matrix)	3		
Maximum Self-Value	3.0967		
Consistency Index	0.0484		
Random Index	0.58		
Consistency Ratio	0.083384313	<0.1	Consistent

3.4. Integrated Classroom Index (ICI) for Educational Spaces

The index was constructed using the previously obtained weights, using the definition of Equation (1) for each design principle. This is presented below:

$$S_{DP} = \sum w_p \cdot (raw_p / max_p), \sum w_p = 1, S_{DP} \in [0, 1] \quad (1)$$

where for each design principle $DP \in \{PR, EC, ST\}$: raw_p is the raw score of parameter p (the sum of its indicators, each scored 0, 1, or 2); max_p is its maximum score; and w_p is the local AHP weight of parameter p within its principle, so that the standardized principle score S_{DP} is the local-weighted mean of its parameters' compliance. For the environmental principle, the factor weights (air quality 0.36, thermal 0.30, acoustic 0.22, and lighting 0.12) are taken from the previously validated environmental block [62].

The Integrated Classroom Index (ICI) is then obtained by combining the standardized principle scores with the principle weights w_{PR} , w_{EC} , and w_{ST} (0.59, 0.32, and 0.09, respectively), as defined in Equation (2):

$$ICI = w_{PR} \cdot S_{PR} + w_{EC} \cdot S_{EC} + w_{ST} \cdot S_{ST}, ICI \in [0, 1] \quad (2)$$

Equation (1) expresses each design principle as the local-weighted mean of its parameters' compliance, standardized to the 0–1 range, while Equation (2) combines the three principles using their AHP weights to yield the ICI. This two-level scheme produces an overall indicator, reported on a 0–1 scale (and as a percentage), that reflects the global quality of the educational space while keeping all principles on a common scale.

The cut-off scores for each category are established by methodological definition (Table 11): Excellent ($ICI \geq 0.90$), Adequate ($0.70 \leq ICI < 0.90$), Sufficient ($0.45 \leq ICI < 0.70$), Insufficient ($0.25 \leq ICI < 0.45$), and Poor ($ICI < 0.25$), complemented by guardrails on the Personalization and Environmental Comfort sub-scores that prevent trade-offs between critical dimensions. These thresholds provide clear, specific criteria for assessing and classifying ICI results regarding the design effectiveness of educational spaces.

Table 11. Global scoring scale. Source: Preparation by the Authors.

Classification	ICI (0–1)	Guardrail	Level of Compliance
Excellent	$ICI \geq 0.90$	$\min(S_{PR}, S_{EC}) \geq 0.70$	Design parameters consistently meet high-performance targets and support multidimensional quality.
Adequate	$0.70 \leq ICI < 0.90$	$\min(S_{PR}, S_{EC}) \geq 0.40$ and $\max(S_{PR}, S_{EC}) \geq 0.70$	Design parameters meet the targets overall; some aspects may require optimization.
Sufficient	$0.45 \leq ICI < 0.70$	$\max(S_{PR}, S_{EC}) \geq 0.40$	Parameters are within the baseline acceptability range; they neither hinder nor fully enable optimal multidimensional quality.
Insufficient	$0.25 \leq ICI < 0.45$	$\max(S_{PR}, S_{EC}) < 0.40$	Significant deficiencies in the critical design principles limit the quality of the educational space.
Poor	$ICI < 0.25$	None	Widespread non-compliance with the design parameters; the quality of the educational space is compromised.

Note: The guardrail conditions are not entry requirements but a cap applied after the ICI band. Following the category-assignment rule (Equation (3)), a classroom's final category is the more severe of the category implied by its ICI value and the highest category permitted by the guardrails on S_{PR} and S_{EC} .

3.5. Category-Assignment Rule and Guardrails

The five performance levels in Table 11 are assigned in two steps that combine the overall ICI value with per-principle guardrails on the two critical principles—Personalization (S_{PR}) and Environmental Comfort (S_{EC}). These principles are treated as critical because they carry the highest weight ($w_{PR} = 0.59$ and $w_{EC} = 0.32$) and, in the case of Environmental

Comfort, capture health-related conditions (thermal, acoustic, air, and lighting) whose deficits are not considered compensable. The Stimulus principle (S_{ST} , $w_{ST} = 0.09$), currently operationalized through visual indicators, contributes to the ICI value but does not impose a floor.

In the first step, a base category C_{ICI} is assigned from the ICI bands of Table 11. In the second step, a guardrail cap C_g is determined from the critical principles. Let $m = \min(S_{PR}, S_{EC})$ and $M = \max(S_{PR}, S_{EC})$; then $C_g = \text{Excellent}$ if $m \geq 0.70$; Adequate if $m \geq 0.40$ and $M \geq 0.70$; Sufficient if $M \geq 0.40$; and Insufficient otherwise. The assigned category is the more severe (lower-ranked) of the two on the ordinal scale $\text{Excellent} > \text{Adequate} > \text{Sufficient} > \text{Insufficient} > \text{Poor}$:

$$\text{Category} = \min_{\leq} (C_{ICI}, C_g) \quad (3)$$

Equation (3) where $\min_{\leq}$ returns the lower-ranked category. Guardrails therefore never raise a category; they only prevent a high aggregate ICI from masking a critical deficit in Personalization or Environmental Comfort. The Poor level is reached only through the ICI band ($ICI < 0.25$). Figure 4 summarizes this rule.

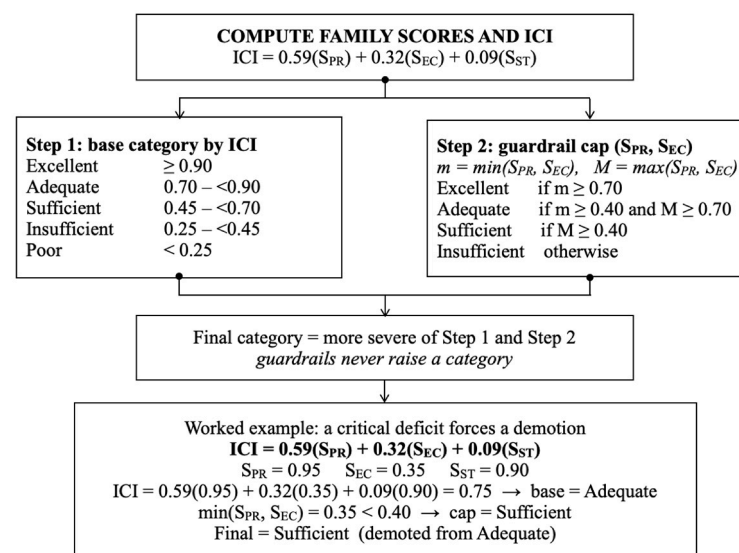


Figure 4. Category-assignment rule: two-step combination of the ICI value and the guardrails on Personalization and Environmental Comfort, with a worked demotion example.

The rule is illustrated by two examples (Figure 4). A classroom with $S_{PR} = 0.95$, $S_{EC} = 0.35$, and $S_{ST} = 0.90$ obtains, from Equation (2), $ICI = 0.59(0.95) + 0.32(0.35) + 0.09(0.90) = 0.75$, which by itself falls in the Adequate band. However, $\min(S_{PR}, S_{EC}) = 0.35 < 0.40$, so the guardrail cap is Sufficient and the assigned category is Sufficient: the classroom is demoted despite an otherwise adequate ICI, because its Environmental Comfort falls below the critical floor. In contrast, a classroom with $S_{PR} = 0.90$, $S_{EC} = 0.55$, and $S_{ST} = 0.60$ obtains $ICI = 0.59(0.90) + 0.32(0.55) + 0.09(0.60) = 0.76$, also in the Adequate band. Here, $\min(S_{PR}, S_{EC}) = 0.55 \geq 0.40$ and $\max(S_{PR}, S_{EC}) \geq 0.70$, so the guardrail cap is Adequate and the category holds. The two cases share almost the same ICI yet resolve to different categories, showing that the guardrails become operative only when a critical principle falls below its floor.

Because the canonical states of the anchor model (Figure 2) take values in $\{0, 0.5, 1\}$, the guardrail conditions are satisfied there by construction; the guardrails thus become operative only for the continuous sub-scores obtained from real classrooms.

4. Discussion

The ICI provides a comprehensive view of the weighting of the design principle and parameters for evaluating or intervening in an educational space. Although other research has prepared indices for investment projects in school infrastructure in Chile, these mainly focus on the material conditions of the infrastructure, basic services, architectural program, security, sustainability, and comfort, not addressing design principles that have been included and validated in this research, providing a new dimension to evaluate educational spaces. Unlike tools restricted to indoor environmental quality, the ICI integrates a previously validated environmental block [62] with the personalization and stimulus dimensions into a single weighted, reproducible, and auditable index, which constitutes its main contribution. Unlike broader frameworks that combine several domains without documenting how their factors are weighted or how their thresholds are derived, the ICI makes the complete assessment logic—from local weights to the category-assignment rule—explicit and repeatable by other teams.

Regarding the weight of each design parameter, Barrett defined that the design parameters of the Nature principle affect student learning, with lighting at 21%, air quality at 16%, and temperature at 12%, having a 59% incidence [9]. From Barrett's individualization dimension, flexibility has an impact of 17% and ownership 11%, totaling 28%. For the stimulus parameters, complexity has 12%, and color is 11%—together 23%. In the Chilean context, the experts indicate that the personalization principle has the highest weight regarding the quality of educational spaces, representing a significant 59%. This is followed in importance by environmental aspects with 32%, and finally, those related to stimulus with 9%. These disparities highlight the overriding need to progress toward local indices, as substantial differences arise from the different social levels. A limitation of the ICI concerns the transferability of its weights. As the comparison with Barrett's UK-based weights above illustrates, the principle and parameter weights reported here are specific to the priorities of the Chilean expert panel and to the national school-infrastructure context, and should not be assumed to hold elsewhere. The instrument itself, however, is designed to be portable: its parameters, indicators, two-level aggregation, and guardrails remain valid, while the weights can be re-derived by re-applying the AHP with local experts in the target context. In this way, the ICI can be adapted to other regulatory and sociocultural settings without altering its underlying logic.

In the definition of the ranges of the categories defined for the global analysis of the ICI, there are differences in the boundary percentages. Tanner defines under 70% as "inadequate", which makes his scale extremely demanding for the compliance of the design criteria [41]. In the case of Minhas and Nair [24], "acceptable" is between 51% and 70%. These discrepancies in the categories' definitions reflect the diversity of approaches to evaluating the quality of educational spaces, highlighting the importance of considering differences within the context where the research is made. The variability in the evaluation perceptions and criteria can be affected by cultural and local regulatory factors or even by the particular aspects of the educational communities evaluated. It is key to recognize that the quality of the educational spaces can be evaluated subjectively and contextually, which underlines the need to adapt the evaluation scales to the specific characteristics of each environment.

Beyond its conceptual integration, the ICI is intended as a diagnostic and decision-support tool. It can characterize the quality of existing classrooms, inform the design of new facilities, and prioritize interventions when resources are limited, by identifying which design principles and parameters most constrain the quality of a given space. Because its scoring, weighting, and classification are explicit, the results are comparable across schools and projects, which makes the index directly usable in school-infrastructure planning

and in the formulation of investment policies, where transparent and justifiable criteria are required.

Several limitations frame the scope of these results and point to future work. The principle and parameter weights are specific to the priorities of the Chilean expert panel and to the national context, so they should be re-derived through the AHP with local experts before applying the index elsewhere. In addition, the Stimulus principle is currently operationalized through visual indicators only, which narrows its coverage. Future work should therefore extend the sensory indicators beyond the visual dimension, re-calibrate and validate the index in other climatic and regulatory contexts, and examine, through longitudinal studies, how design improvements relate to educational and well-being outcomes.

5. Conclusions

The main scientific contribution of this study is the development of the Integrated Classroom Index (ICI), an original multi-criteria index that integrates personalization, environmental comfort, and stimulus into a single, transparent, and reproducible assessment framework. The design parameters were derived from an exhaustive literature review and validated by a panel of 42 interdisciplinary experts through a Kappa concordance analysis; a specialized subgroup of 18 of them then assigned the weights through the AHP. The resulting weighting shows that personalization and environmental comfort mainly determine the classification, whereas the stimulus parameters have a limited impact, in line with the weights assigned to the principles. By making its weights, thresholds, and classification rule explicit, the ICI provides an auditable and repeatable basis that distinguishes it from previous, less transparent instruments.

In practical terms, the ICI is intended as a diagnostic and decision-support tool for researchers, architects and designers, and public authorities. It provides a clear and objective framework to compare learning environments, to guide the design and diagnosis of school spaces, and to prioritize interventions. This is particularly valuable for decision-making on public investment in educational infrastructure, which often operates under significant financial constraints and therefore requires transparent and justifiable criteria to identify the factors that most affect the quality and efficiency of school buildings.

Future research should broaden the sensory dimension beyond its current visual scope and validate the index in other climatic and regulatory contexts, since the weights reflect local priorities. Progressing toward such context-specific indices, complemented by longitudinal studies that relate design improvements to educational and well-being outcomes, is a crucial step for understanding and addressing the variability of educational settings.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki. Ethical review and approval were waived for this study because it involved anonymous surveys of professional experts on non-sensitive, opinion-based design criteria, with no collection of personal or health-related data.

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The data presented in this study—the multicriteria matrix, the expert weighting matrices, and the classroom scoring datasets—are available on request from the corresponding author. The data are not publicly archived due to privacy considerations regarding the participating schools.

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Appendix A

Table A1. Design parameters presented by different authors.

Design Principles	Design Parameters	[27]	[26]	[47]	[3]	[41]	[28]	[86]	[5]
Personalization	Values and connection with the community								
	Cozy access to the establishment		•						•
	Global aesthetics of the center								•
	Symbols of belonging			•		•			•
	Security of the establishment						•		
	Spatial Appropriation								
	Classroom features enable a feeling of ownership			•	•			•	•
	Students are provided with suitable space				•	•		•	•
	Exhibition area inside the classroom	•	•	•	•	•		•	•
	Personalized elements within the classroom	•		•	•			•	
	Flexibility within educational spaces								
	Sufficient space between activity areas	•	•	•		•		•	•
	Learning zones within the classroom	•	•	•	•	•	•	•	
	Incorporates flexible elements between classrooms	•		•		•	•	•	
	Integration of the corridors into learning activities				•	•		•	
	Flexibility between classrooms and the hallway		•						
	Furniture that supports flexibility	•		•			•	•	
	Educational Privacy Oasis								
	Indoor Quiet Areas		•	•		•		•	
	Indoor Private Spaces for Children’s Socialization		•			•		•	
	School Furniture								
	Quality of the furniture and equipment	•	•	•	•			•	•
	Comfort and size of the desks/ tables and chairs		•		•		•	•	

Table A1. Cont.

Design Principles	Design Parameters	[27]	[26]	[47]	[3]	[41]	[28]	[86]	[5]
Environmental	Thermal								
	Classroom temperature	•					•		
	Solar gains by orientation				•	•			•
	Central heating system		•		•		•		•
	Air Conditioning		•				•		
	Acoustic								
	Frequency of noise disturbance inside the classroom		•						
	The degree to which the pupils can hear clearly what the teachers say	•			•		•		•
	Noise from the school outside				•		•	•	•
	Internal noise: Computers and equipment						•	•	•
	Reverberation inside the classroom						•	•	
	Soft, sound-absorbing surfaces							•	
	Lighting								
	Daylight quantity	•		•	•	•	•	•	•
	Daylight control (i.e., blinds)								
	Artificial light quantity	•		•	•	•	•	•	•
	Artificial light control (i.e., light switch possibilities)								
	Exterior views			•	•	•	•		
	Visibility to the whiteboard and project						•		
	Air Quality								
	Air quality in the classroom	•					•		
	Smells in the classroom						•		
	Ventilation rate (volume vs. number of people)				•	•			•
	The possibility of air quality control (window opening)				•				•
	Surface area or percentage of windows to ventilate								
	The use of the ventilation system				•		•		•
Stimulus	Nature connection								
	Exterior view			•	•	•	•	•	•
	View Type					•		•	•
	Accessibility to spaces containing biophilic elements		•		•	•		•	•
	The classroom has different biomorphic shapes and patterns							•	
	Color Integration								
	Classroom color	•	•	•	•		•	•	
	Colors of blinds, carpet, chairs, desks		•	•	•			•	

Appendix B

Table A2. Maximum scores and weighting calculation procedure of the Integrated Classroom Index (ICI).

Design Principle (Weight)	Parameter	Local Weight (w_p)	Max Score ($\max_p$)
Personalization ($w_{PR} = 0.59$)	Spatial Appropriation	33%	6
	Spatial flexibility	27%	12
	Cultural belonging	24%	4

Table A2. Cont.

Design Principle (Weight)	Parameter	Local Weight (w_p)	Max Score ($\max_p$)
	Spatial privacy	11%	2
	Furniture	5%	2
	Subtotal (M_{PR})	100%	26
Environmental ($w_{EC} = 0.32$)	Air quality	36%	10
	Thermal	30%	10
	Acoustic	22%	10
	Lighting	12%	10
	Subtotal (M_{EC})	100%	40
Stimulus ($w_{ST} = 0.09$)	Connection with nature	90%	8
	Color integration	10%	4
	Subtotal (M_{ST})	100%	12

Each principle is standardized as $S_{DP} = \sum w_p \cdot (\text{raw}_p / \max_p) \in [0, 1]$, using the local weights (w_p) and maximum scores ($\max_p$) above; the ICI is then $ICI = 0.59 \cdot S_{PR} + 0.32 \cdot S_{EC} + 0.09 \cdot S_{ST}$ (Equations (1) and (2)). Source: preparation by the authors.

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