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Thriving children's perceptual learning through educational environments color and material design

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Abstract

Being the place where children spend most of their daily lives, the educational environment plays a crucial role in children's cognitive development. Indeed, pedagogy recognizes the role of space as the "third teacher," promoting the importance of the interior environment's multisensory quality, which can stimulate "perceptual learning," - especially considering children aged 0-6 years - which is a progressive improvement in perceptual skills, nurtured by the direct experience.

Through case study analysis and literature review, the paper aims to identify and categorize some color-material design strategies within educational interior environments, highlighting how this complexity can be related to multiple pedagogical and cultural factors.

The multisensory features of colors and materials resulting from the above-mentioned aspects bring the outside world richness into the educational environment, training children to relate to and act within the complexity of the existing world (local and global, analog and virtual), while quantifying the effectiveness of this approach remains an open field of research.

Introduction

The educational field is currently receiving considerable international attention and financial investment, witnessed and promoted by the fourth of the 17 Sustainable Development Goals concerning Quality Education, to ensure inclusive and equitable opportunities for all. Moreover, children's spaces are increasingly becoming, especially in European countries, the places where large population movements (migrations and other nomadism) reveal themselves, sharing growth experiences and involving cognitive aspects from different cultures, offering relevant opportunities for inclusion (Maxwell, 2014). In fact, according to the *Ecological Systems Theory* (Bronfenbrenner, 1979), children's development is influenced by a series of systems, seen as concentric circles where the child is at the center. *Microsystems*, such as school and home, are the closest environments to the individual.

Nevertheless, the scientific literature often refers to *Quality Education* typically linked to the pedagogical approach, neglecting the impact of the

school environment, intended as spatial design with its color-material-shape features. Indeed, despite infant and toddler schools being the places where children typically spend most of their time, interior design is not as well supported by analytical studies on the various aspects that define educational spaces.

The overall objective of the paper is to investigate the role of interior design, and its multisensory aspects in educational environments, to observe if and to what extent it can impact a child's cognitive development. Indeed, human beings have different sensory systems that contribute to the processing of information and knowledge and that are activated, alone or combined, by the external environment, and infancy is a crucial period where multi-sensory experiences foster a person's proper cognitive development (Dionne-Dostie & al., 2015). In these early years our perceptual abilities are refined thanks to a phenomenon known as *perceptual learning*, made possible by *neuroplasticity*, i.e. the ability of our brain to adapt its structure in response to external stimuli.

Among the various sensory aspects, the preliminary literature review has shown that color is a major player in our perceptual and psycho-physiological experience as it influences various functions of the mind and human behavior, such as vision, scene perception, object recognition, aesthetics, and communication, defining a research field that touches different disciplines (Maule, Skelton & Franklin, 2023).

Therefore, the paper's specific objective is to explore how co-stimuli are managed within the 0-6 spaces, attempting to highlight possible strategies and helpful insights for advancing research in this field. The analysis is based on a literature review, which integrates pedagogical and neuroscientific components to support the design and proceeds through the examination of selected case studies.

The research efforts focused initially on the neurological aspects of child cognitive development, particularly concerning sensoriality and arising mainly from the 1970s and 1980s: the goal at this stage was to understand whether the multisensory environment could be implicated in this process. In the same years, in Italy, the sensory and immaterial aspects were explored within the Primary Design. This research was a turning point for color design, revealing that color cannot be mediated but it can impact on our spatial perception, depending on how it is applied. In addition, some perspectives, such as Frank Mahnke's one, attempting to combine design and psychology or neuroscience, note how the variety of stimuli can help children's cognitive development. Pedagogy widely recognizes the fundamental role of sensoriality in childhood education, even if it addresses it through different approaches. In particular, the Reggio Emilia Approach promotes multi-sensory environments as a result of the collaborative efforts of educators, researchers, and designers.

Literature Review

Children, particularly in the 0-6 years, are exceptionally curious and inclined to explore the space around them and learn from it. Indeed, some pedagogical approaches define the space with the term 'third teacher' as it contributes to the cognitive development of young children (Fraser, 2000; Wien, 2008).

Child cognitive development and perceptual learning

In the early years of life, the human brain shows incredible capacities for adaptation and inclination to learn, meaning that every experience can have an enormous effect on an individual's mind and personality. In neuroscience,

this capacity is known as *neuroplasticity*[1] consisting of the brain's ability to create, organize, and eliminate *synapses*, i.e. neural connections, between different neural regions during its development.

Within the different types of learning capabilities of our mind, *perceptual learning* consists of improving, through direct experience, our perceptual abilities, such as the possibility of distinguishing similar shades of color. Early studies date back to the mid-19th century; however, since the 1980s, this natural, unconscious phenomenon has gained increasing attention due to new knowledge in physiology and neuroscience.

The contribution of neuroscience in the design of spaces has recently been widely experimented, specifically dealing with light and colors, within the framework of facilities dedicated to adults and children affected by mental and cognitive diseases. Well-known examples are the *Snoezelen* rooms, i.e. controlled multisensory environments designed to induce well-being in individuals with learning disabilities, autism, cognitive impairment, or other pathologies (Hulsegge & Verheul, 1987). Within these rooms, widespread in the Netherlands since the 1970s, it is possible to control the nature, quantity, and intensity of sensory stimuli with the help of specialized operators, creating relaxing and optimal environments. However, the literature does not report an equal amount of attention in extending this research to other spaces generically dedicated to children.

Primary Design and the role of soft qualities in the environment perception

The importance of the sensorial dimension became an important design topic of practical and theoretical research, especially in Italy, concerning the Primary Design Approach. In the Seventies, Clino Trini Castelli identified the role of some aspects, defined as 'subjective' of the quality of space, characterized by a 'soft' nature and a 'low energy,' which, if used in a particular widespread modality, can strongly modify our perception of the environment. He defined 'Primary Design' as the adoption of these effects - such as smell, light, and color - at a large scale (Thomas, 1996). From these observations emerges the relevance of *soft qualities*, meaning the intangible values of space - colors and materials - as opposed to *hard qualities* - form, function, and ergonomics - considering the former no longer seen as subordinate to the latter but designed in synergy.

To better express these theories, Branzi and Castelli also adopted the metaphor of *bradyseism*[2], since its effect, as well as that of the intangible qualities of space, is imperceptible on a small scale, but very relevant on a large scale (Branzi & Castelli, 1984): for example, the same color applied in a minimum way in an environment is not able to change our perception of that environment, but it can become relevant if applied intensively.

Clino Trini Castelli also introduces the concept of *qualistic*, defined as the perception of subjective quality: unlike hard qualities, soft qualities cannot be mediated. The consequence is the need to consider how the same color can not only please one individual and not another, but also provoke different emotions.

Environmental stimuli for cognitive development: contrast and time

Hence, color must be an influential component to modify our perception of that space and our related emotions and physiological responses. The belief that such responses are not generalizable, as they are mediated by multiple factors, is widespread and supported by Frank Mahnke with his *pyramid of color experience*.[3]

Over the decades, many researchers have explored the topic of color in interior design and its implications at the psycho-physiological level. Hugo Kükelhaus advocates the importance of contrast and variety of stimuli within the environment, to the extent that he believes that "monotonous materials or colors can also cause dysregulation" (Meerwein, Rodeck, & Mahnke, 2007, p. 63).

> "It is important to take into consideration the amount of color stimuli (degree of colorfulness) and stimuli variations (contrasts) that are beneficial to the individual." (Meerwein, Rodeck, & Mahnke, 2007, p. 71)

Based on these and other previous theoretical research, Mahnke believes that the non-use or incorrect use of color can have major psycho-physiological implications on the person. Furthermore, he opposes the achromatism, that is mostly typical of offices and schools, where white and neutral colors are used indiscriminately, as scientific studies do not support it. Regarding preschool environments, he claims that to enable children to live different experiences and foster cognitive development, it is appropriate to create rich environments, being careful not to make them either under- or over-stimulating.

Under stimulation occurs notably in monotonous environments, as our minds demand alternating stimuli. Tornquist (1999) recalled the importance of control over color contrast between contiguous rooms, arguing that monochromatic interiors also trigger the phenomenon of adaptation: independently from the initial reaction to the color of a room, responses will decrease over time. Indeed, according to Meerwein, Rodeck, and Mahnke (2007) environments within which more time is spent require greater attention than spaces that are transitory, or of occasional and/or brief use.

> "The color schemes of spaces where people spend large amounts of time should be unobtrusive yet expressive enough to accommodate the personal design preferences, imagination, creativity, and freedom of each individual user. Instead of overpowering us, colors should serve our needs. We should find them stimulating, not annoying". (Meerwein, Rodeck, & Mahnke, 2007, p. 71)

Both Meerwein, Rodeck and Mahnke's and Tornquist's writing address some design guidelines because of their studies: all of them agree on the importance of balanced contrasts, also with light. According to the first ones, the color of the ceiling should be lighter than that of the walls, and that of the floor darker. According to Tornquist, walls, preferably opaque with medium reflection, if windowed should be light sufficient to avoid contrasting with outside light, while if opposite to windows should not be too saturated not to alter light reflection, similarly to ceilings.

Color in interior environments through pedagogical approaches

Despite the widespread recognition of the significance of sensory stimulation during childhood, some pedagogical models have slightly different approaches to achieving it. An internationally recognized example that focuses on the importance of the physical space in education is the Reggio Emilia Approach, introducing the concept of 'third teacher'. Indeed, conducting joint research between pedagogy and architecture over the years, Reggio Children promotes the idea of multi-sensoriality within its spaces, where every child should be able to find the stimuli he or she prefers and pursue curiosity and creativity. The authors of "Bambini, spazi, relazioni. Metaprogetto di ambiente per l'infanzia" (Ceppi & Zini, 1998), also use the

terms *soft complexity* and *rich normality*, stating that school environments should be composed of a multitude of different elements and sensorial features spread throughout the space, since children are considered as a laboratory for the senses with a synesthetic capacity (Zini, 2024) following the abovementioned metaphor of bradyseism.

The Reggio Emilia Approach, originating with Loris Malaguzzi (1920-1994) in the 70s, refers to the child as a complex and competent human being having a *hundred languages*, i.e. multiple ways of interfacing and communicating with the world, that can be translated into spatial choices as well. According to this belief, the applicative strategy of color should move away from simplistic visions of the infant, associating them only with primary or pastel tones, and developing a complex landscape with the coexistence of composite colors and materials of different natures. Malaguzzi fosters the employment of materials that capture the children's interest, encouraging their sense of aesthetics and the discovery of the surrounding space. In proposing this multisensory stimulation, he departs from the Montessori perspective, which focuses on the *single qualities* of teaching materials.

> "[…] unlike other pedagogies that can be guilty of treating early infancy as a preparation for later childhood and adulthood, and consequently seeing nursery education as a kind of antechamber to later stages of formal education, the Reggio Approach considers early infancy to be a distinct developmental phase in which children demonstrate an extraordinary curiosity about the world." (Valentine, 1999)

The Montessori Method pursued a different approach which aims to enable the child to become independent and responsible through the completion of certain tasks. In this perspective, the space is generally neutral and features the presence of wood - even if there are no precise guidelines in this sense. Montessori education prioritizes learning through materials that have a unique quality, avoiding secondary features that could deflect the child's attention away from the target of the exercise: color training, for instance, takes place through boards with nine color hues of silk thread in seven nuances each (Zuccoli, 2018). According to some pedagogists and educators, a critical issue that may emerge from this approach is indeed the risk of over-processing and selection of sensory stimuli since these isolated components are not found in the real world, which is made up of complexities, overlaps, and distractions.

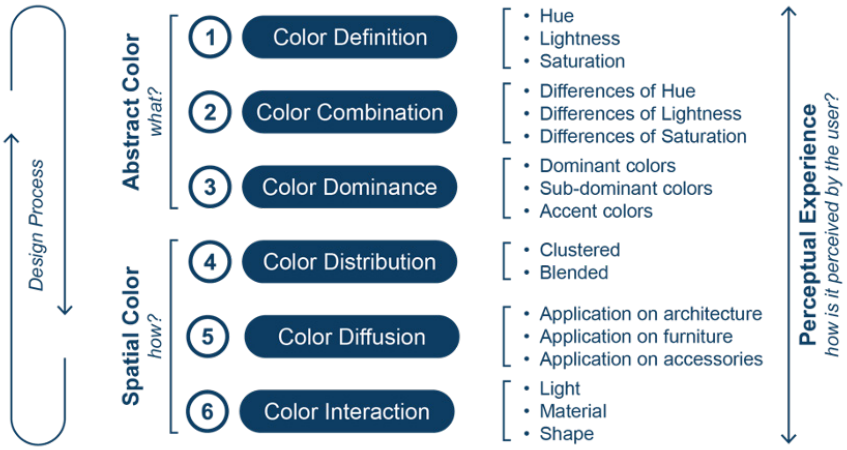
Methodology

International case studies were reviewed to explore how color is managed within 0-6-year-old environments. This analysis is intended to detect different ways of application of color that may be useful for advancing a research activity that pursues the enhancement of the design approach of educational spaces for children. The literature review found that a variety of stimuli helps promote cognitive development by fostering perceptual learning. Furthermore, different hues within a space allow all children to find their favorites (Ceppi & Zini, 1998), thus enhancing their feeling of well-being and comfort.

For the selection and analysis of the case studies, some variables that could provide sensory stimulation were derived from the reference literature and visualized in a diagram where they are ordered by an increasing relationship to physical space.

To obtain a variety of stimuli, *color combinations* can be created based on "differences in color tones (contrasts in chroma), differences in saturation (contrasts in color intensity), differences in brightness (contrastsin degree of luminosity)"; moreover, it is possible to discern dominants, subdominants, and accents based on the ratio of the different colors within a space (Meerwein, Rodeck, & Mahnke, 2007, p. 71-72): dominant colors are most present and determine the atmosphere of the space and should not overstress the eye. These features can be considered part of color presence, indicating what we find within a space and to what extent. Adopting the interior design perspective, it is also crucial to observe how color is applied in the space: for example, whether color is limited to complements, or also found in furniture and architectural elements, and whether it is applied in a blended or clustered manner.

Figure 1. Diagram of factors influencing color-material complexity



In addition, color must always be considered in relation to light, shapes, and materials. within a space, as well as in relation to the perceptual experience of the inhabitant, since color strongly depends on the context and the perception of the observer (Boeri, 2013).

The selected case studies all concern educational environments involving the 0-6 age group, excluding other types of childcare spaces, such as playrooms or other facilities that may be used only occasionally. They do not have the same color design requirements due to less time spent there, resulting in less influence on the child's cognitive development.

Figure 2. Sensory area of Daycare Centre WeltenBummler. Design by Baukind, Photo by HEJM.

A. Daycare Centre WeltenBummler

The Daycare Centre Weltenbummler, opened in 2019 in Berlin, welcomes children aged 10 months to 6 years, while pursuing the principles of the 'Berliner Bildungsprogramm', focused on play and exploration. The interior design was conceived by Baukind, Weise Architects, and Gewers Pudewill Architects.

The white classrooms all contain a monochrome sensory area with different elements that do not have specific functions but open up multiple possibilities for use, play, and exploration. These areas feature not only furniture but also walls, ceilings, and floors in the same color. According to the educational model, children are divided into homogeneous age groups and change classrooms yearly. The chromatic concept is 'my color, my group': each classroom is identified by a specific chromatic scheme. The lower floor, housing the toddlers, has softer hues than the upper floor, which accommodates children from 4 to 6 years old, while common areas, such as bathrooms, outdoor facilities, and the changing room, combine the different colors.

The color shows mid-saturated tones with rather low blackness. Multiple tones are present on the overall scale, although only one or two hues within the single classrooms. The color distribution follows the logic of dedicated monochrome areas, having one or two dominants in each room, affecting both the furniture and the architectural envelope.

In this instance, color plays a *wayfinding function*, helping the child to recognise where he or she belongs. However, this approach lacks multi-sensoriality within the single spaces.

B. Agora International School

Figure 3. Part of the 3-5 years old common area of Agora International School. Design by Rosan Bosch Studio – Photo by Kim Wendt.

The Agora International School in Madrid provides education for children and teenagers along the principles of IB (International Baccalaureate). In 2022, Rosan Bosch finalized the children's areas, aiming to support active learning and creativity.

The architectural shell is almost entirely white, creating a contrast with the elements placed in it. The floor is divided between the 1-2-year-olds and the 3-5-year-olds, with a light blue path connecting all the elements of the common areas. There are various structures and furnishings, especially in the common areas, intended for play, marked by rather saturated and diversified shades: as a result, each area acquires a strong visual connotation. The classrooms are also recognizable by their colors, which are fainter, such as lilac and light blue, in the rooms dedicated to toddlers, and more saturated, such as blue and red, in those dedicated to older children. The color presence is composed of moderately saturated tones with mainly low blackness. Multiple tones are present overall and in the common areas, while the classrooms predominantly present one. The color distribution mainly affects the furniture and structures, presenting several dominants

and subdominants that may differ from one area to another.

This chromatic approach involves the use of primary colors, bright and iconic, disseminated and isolated on a white base: the result is a high-impact aesthetic, but limited material and multi-sensory complexity.

C. Fjellvegen Barnehage[4]

Fjellvegen Barnehage is one of the Tromsø kindergartens, hosting 1-5-year-olds, built in 2006 and designed by 70 N Arkitektur. The Norwegian Barnehage curriculum is also based on play and discovery.

The interior spaces of the kindergarten are flexible and equipped with playing movable walls that can create diversified and multifunctional micro-environments: each mobile structure is different and enables a variety of activities, from drawing to climbing, and has several holes of various sizes and shapes. The interior architecture is predominantly white, with some fixed monochrome walls while others highlight the organic shapes of the openings using different shades; overall, colors are combined throughout the space together with some natural materials such as wood. The color presence within the space varies, tending to present medium saturation and not excessive blackness. The distribution of color also varies, affecting furnishings and accessories as well as entire fixed walls. It is impossible to distinguish one dominant shade, but instead, several accents.

In this instance, color emphasizes the irregular shapes of the spatial components and movable walls, enhancing the design concept. The various areas present diverse varieties of stimuli, leading to differing levels of multi-sensoriality.

D. ENI Nursery and Kindergarten

Figure 4. 3-6 classroom of ENI Nursery and Kindergarten. Photo by ZPZ Partners.

The ENI Nursery and Kindergarten was opened in San Donato Milanese in 2009 because of a collaboration between Reggio Children and the University of Milano Bicocca. The project was developed by ZPZ Partners, Tullio Zini, and Lapis Architetture. The colour strategy used in this project is representative of that employed in most of the Reggio Children Approach schools.

The building embodies its pedagogical principles, including the osmosis between interior and exterior and multi-sensoriality, aimed at promoting the child's free expression and his 'hundred languages'. The design of soft qualities, and color, plays an important role in the realization of these spaces. The interiors feature wooden floors and ceilings, while some walls have different shades, never juxtaposing two complementary ones. The furniture, instead, has more saturated colors and various shades that are mixed within

the space. The only differing space is the atelier, i.e. the experimental laboratory, located in a different pavilion: in this case, the wooden ceiling is replaced by a yellow one, as well as the furniture is predominantly lighter, in white, and a few tones of yellow and orange.

The color presence is characterized by low blackness, various shades, and medium saturation, lower on the walls and higher on the furniture. The distribution of color within the space is diffuse and uniformly applied in the furniture and some walls: in this case, all the shades are equally dominant.

The project creates a variegated multisensory ecosystem involving architecture, furniture, fittings, etc, employing intrinsic and filmic colors. It also engages the synesthesia, achieved by combining different sensory aspects, such as sounds and smells.

E. Le Blé en Herbe

Figure 5. Kindergarten classroom of Le Blé en Herbe. Photo by Philippe Peron.

The 'Le Blé en Herbe' project resulted from the renovation of a school in Trébédan, to consolidate its role in the socio-cultural life of the city. It was opened in 2015 and welcomes children from kindergarten and elementary school, 2–10 years old. The educational approach is inspired by Montessori, fostering children's autonomy and movement, and Freinet, an exponent of popular pedagogy, advocating active learning that occurs through trial and error.

In this case, the floors and walls are largely tinted in bright tones such as green, blue, magenta, and orange, leaving room for a wooden floor and white on some walls and the ceiling. Furnishings are made of wood and metal, combining the natural color of the first one with the overlaid one of the second. Hence, the color presence is composed of different shades with rather high saturations, higher on the furniture than on the structural elements, and low blackness. The color distribution is extensive, leaving little space for white. Each room has one or two dominant colors which are the ones of floorings or walls, and some accent colors on furniture.

Even in this case, the color palette is articulated, composed of filmic and intrinsic colors, with a limited number of shades but applied in an immersive manner.

F. KNO Nursery[5]

KNO Nursery by HIBINOSEKKEI and Youji no Shiro, built in 2019, and located in Nagasaki, aims to encourage young children to read books by providing different reading corners. Most of the case studies observed in this geographical area show a reduced range of hues, opting instead for neutral tones and the use of natural materials such as wood.

This case study achieves a certain color-material complexity with the use

of natural materials, without filmic colors. Such materials, as wood, do not feature a uniform colour but different veins or shades: the range of hues is restricted, providing a greater contrast of blackness or saturation.

Findings

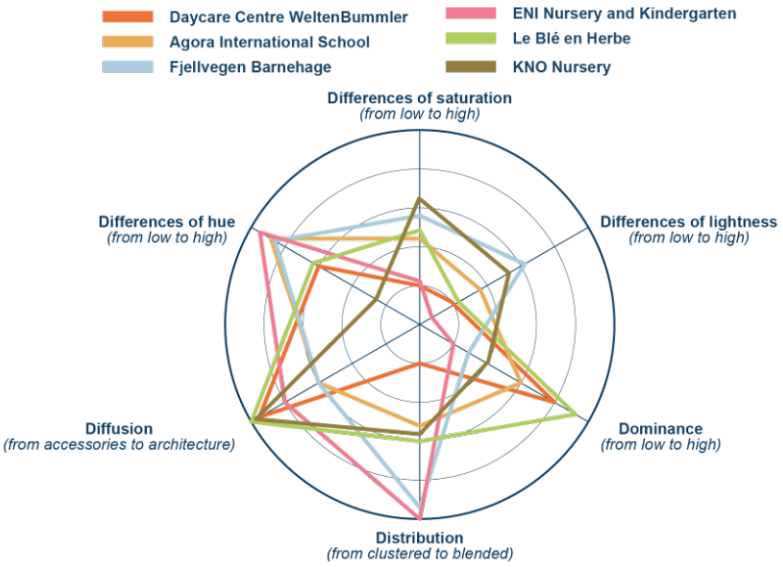


Figure 6. Radar chart of the selected case studies

The analyzed case studies reveal a variety of color strategies, which do not depend solely on pedagogical factors. Some quality parameters, regarding color presence and distribution, are compared and visualized in a radar chart that highlights a condition of under-stimulation at its center and of over-stimulation on the outer circumference. The reported projects show a certain balance to obtain a variety of stimuli that are neither insufficient nor excessive.

In addition to the cognitive or pedagogical function, the analysis also revealed the function of colour as a signal that instead does not guarantee the complexity that can foster the pedagogical perceptual development.

In general, a *gradient of color* diffusion within kindergartens can be discerned, starting from achromatic or neutral spaces to color-laden spaces. Some projects, mainly Montessori-inspired, use only neutral tones leading to a less active environment from a cognitive stimulation point of view. However, it is worth mentioning that even without filmic colour, a good level of complexity can be achieved by using a variety of natural materials, such as wood.

Other cases present *monochromatic sensory areas*, having less color variety within each space and greater variety considering the overall design. As mentioned in the literature review, creating monochrome areas may result in comfort or discomfort depending on the individual's preferences, as well as leading to the phenomenon of adaptation. A *polychromatic interior* provides a variety of visual stimuli for children, resulting in the absence of adaptation and the possibility of finding the stimuli that best suit everyone. In some examples, hues are arranged in rather homogeneous groups or by categories within the space, having one dominant color for each area; in other cases, the same colors are mixed randomly in the space, with all hues being equally dominant. The clustered layout may be less stimulating than a blended one, as the former is more like the monochrome area approach, although there are no specific scientific studies to support this.

A common tendency, although not always verified, is to *keep the architectural envelope more neutral or less saturated* than the furniture components. This allows spatial *transformability* in the short and long term: the application of color on furniture, or even superficially on walls, is easily reversible without architectural intervention.

Another finding worth mentioning is that this attention to color is mostly found in private schools or those with a high budget to spend on design. When directly observing various community locations, such as those run by third-sector associations, in-depth interior design that considers the perceptual implications of color is rarely found, and primary colors are often used without logic or distinction. This is also due to the market that only in rare exceptions produces furniture in multiple shades of color.

As stated by Reggio Children, and by Ceppi and Zini (1998), children discover the world through the five senses, deserving a varied and articulated environment from a sensorial point of view, in terms of colors, lights, materials, smells, temperatures, that activates synaesthesia and supports cognitive processes. Design responds to this need, considering multi-sensoriality as a qualitative requirement. It follows that some approaches (case studies D and E) take this pedagogical requirement into account, some (A) not at all, and some (B, C) only slightly.

Conclusions

The subject of neuroscience applied to interior design deserves further study and greater dissemination to produce environments that best meet pedagogical requirements. Research about the issue of color in educational environments shows how the presence of different sensory stimuli can foster a child's cognitive development and the phenomenon of perceptual learning. Nevertheless, the lack of on-site surveys causes a shortage of data on the impact of these environmental strategies on small users, contrasting the establishment of priorities and research guidelines. Further advances in research could contribute to indicating some guidelines that can emphasize the active role of physical space in children's learning, maximizing its "third teacher" function. A possible solution could be to promote an increasing interdisciplinary approach, involving different designers, such as landscape designers, interior designers, light designers, and so on, but also pedagogists and experts in the field of child neuroscience.

Footnotes

[1] The pioneer to use the term plasticity in this context was William James, an American psychologist, who defined it as the skill of the brain structure to be weak enough to be influenced but strong enough not to bend completely (James, 1890, cited by Gilbert, Sigman & Crist, 2001, p. 681).

[2] Bradyseism is a phenomenon that consists of tectonic movements that we are unable to perceive but which cause a lowering or raising of the ground level, from our point of view 'slow' but very rapid from a geological point of view.

[3] Mahnke define six aspects that are affecting our color perception and experience: biological reactions to a color stimulus, collective unconscious, conscious symbolism and associations, cultural influence and mannerism, trends, fashion and style, and personal factors (Meerwein, Rodeck, & Mahnke, 2007, p. 20-21)

[4] Photos: https://shorturl.at/rjqOx

[5] Photos: https://e-ensha.com/en-kno-nursery/

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