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Re-naturalizing the built environment. Plants, architecture, and pedagogy in contemporary green schools

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This study discusses the essential need of re-naturalizing the built environment, focusing on schools. Leveraging research on the impact of nature on health, children's development, and learning, we analyze case studies from America, Asia, and Europe with distinct trajectories of interplay between architecture and pedagogy. Using a theoretical framework on plant-architecture relationship, we identify effective re-naturalization solutions in some applications of biophilic design in rural and urban contexts, cautioning against superficial nature incorporations in schools. Our study asserts that technological sustainability is needed but insufficient, emphasizing the necessity of concurrent efforts in architecture and education to create meaningful student-nature connections.

KEYWORDS

schools, education, architecture, biophilic design, sustainability, plants, renaturalization

1 Introduction

Western culture, transitioning from humanism to positivism, associates the naturalness of vegetation with the wild, contrasting it with an 'ideal city' featuring a mineral and metaphysical backdrop. Urbanization, the primary human settlement form (United Nations, 2019), has predominantly entailed the removal and sporadic reintroduction of natural vegetation. The relationship with the vegetal component is limited to productivity or symbolic functions, serving spiritual practices, education, decoration, or celebration. Departing from the evolutionary history of the human species, which thrived through the constant exposure to a verdant environment (Kellert and Wilson, 1993), nature has been increasingly sidelined in daily life in urban spaces. In modern and contemporary cities, nature encounters are limited, sporadic, and typically exclusive to privileged segments of society (Beatley, 2011; Baró et al., 2021).

Indeed, many of the challenges in urban living, pertaining to health, psychophysical balance, and holistic well-being, are linked to limited exposure to nature (Hartig and Kahn, 2016). This is particularly pertinent in light of the 'biophilia hypothesis' (Wilson, 1984; Kellert and Wilson, 1993), which posits that humans inherently seek connections with nature and other life forms. However, this predisposition only fully develops if consistently nurtured from early life stages; otherwise, it diminishes. Outdoor activities, environmental education, and various forms of nature exposure are crucial for nurturing the biophilic tendency and

enhancing well-being (Kellert, 2003). In urban settings, where opportunities for such connections are limited, the creation of spaces facilitating them becomes imperative. This essential re-naturalization not only has the potential to enhance human health and well-being but also to encourage behaviors, values, lifestyles, and strategic choices that support the overall preservation of nature, a critical consideration for our survival.

The importance of enhancing the connection with plants and nature is recognized in various national and international agendas, and explicitly emphasized in the United Nations' Agenda 2030. Operationally, though insufficiently, this recognition informs projects intervening in various aspects of urban life, including public spaces, residential areas, workplaces, and spaces for production, consumption, and services.

1.1 Beneficial effects of nature on wellbeing and personal growth

There is a growing body of scientific research indicating a positive correlation between nature presence and health and well-being, contrasting with the detrimental effects of its absence (Hartig et al., 2014; Kuo, 2015; Bratman et al., 2019). Limited exposure to nature has been linked to various health issues, including childhood obesity (Lachowycz and Jones, 2011; Wolch et al., 2011), respiratory illnesses, and impacts on immune system functioning (Chawla, 2015), collectively termed 'Nature-Deficit Disorder' (Louv, 2008). Although the original interpretation of the concept has been questioned (see Dickinson, 2013), Louv's term encapsulates the absence of nature and its broad range of associated effects.

Numerous studies focus on the impact of nature contact on the education, physical development, and cognition of young populations. Notably, Dadvand et al. (2015), along with reviews by Chawla (2015) and Kuo et al. (2019), extensively explore these themes. Regular nature exposure has been shown to facilitate various aspects of personal growth and learning, including self-awareness, self-discipline, self-confidence (Faber Taylor et al., 2002), critical thinking, adaptability (Kuo, 2001), prosocial behavior, cooperation (Goldy and Piff, 2020), and creative play (Taylor et al., 1998). Furthermore, as evidenced by earlier seminal research, contact with nature reduces stress, aids attention restoration, and promotes overall psychophysical well-being (Ulrich et al., 1991; Kaplan, 1995, 2001).

1.2 The role of schools in the ecological transition

Research indicating the positive impact and necessity of nature exposure on the personal growth and health of young people underscores education as a critical and promising domain for the imperative transformation of inhabited spaces. Scholars have shown that incorporating nature in schools enhances cognitive performance (Benfield et al., 2015; Li and Sullivan, 2016), even for students with attention deficits or neurodevelopmental issues (Kuo and Faber Taylor, 2004; Faber Taylor and Kuo, 2009; Stevenson et al., 2021). It also boosts ecological sensitivity (Otto and Pensini, 2017) and psycho-physical well-being, benefiting not only students but the entire school community (Kuo et al., 2019).

Schools, as institutions, shape social relations and hold considerable civic and symbolic importance in society (Reichelt et al., 2019; Wood, 2020). They serve as spaces for experimenting with the relationship with nature and as instruments for promoting awareness about environmental sustainability, plant benefits, and other aspects of natural life. Hosting a substantial part of young people's lives, schools materially influence judgments, behaviors, and the development of cognitive and relational abilities (Park and Lee, 2019). In this democratic capacity, schools can mitigate social, economic, and educational inequalities. Their widespread distribution and daily use by a diverse community, including students, educators, staff, and indirectly, parents, magnify their significance.

As asserted by Baró et al. (2021), school environments can alleviate disparities in urban access to nature, particularly in domestic settings. This is crucial for safeguarding the right to physical and mental health and ensuring equal opportunities for personal development. Such democratic role of school environments became apparent during the schools shutdown connected to the COVID-19 pandemic, when socioeconomic inequalities significantly impacted both learning quality and the overall well-being of confined young individuals. Factors such as the size and the privacy of the available home spaces, presence of plants, accessibility to terraces and gardens, views of nearby natural elements or landscapes proved crucial (Chiesi and Costa, 2022).

1.3 Forest schools, green schools, and biophilic design in schools

Two primary educational trajectories aim to enhance the connection with nature.

Initially, experimental educational models recognized nature's value for personal growth before scientific evidence confirmed its benefits for learning and cognitive development. Since the 20th century, Swedish "I Ur och Skur" (With Sun and With Rain), Norwegian "Natur-og friluftsbarnehagen" (Outdoor Schools), English "Forest Schools," and German "Waldkindergarten" (Forest Kindergarten) emphasized outdoor activities and immersion in natural, uncontrolled settings in their educational approaches (Antonietti, 2018). These "forest schools" experiences highlight a strong relationship between school spaces and outdoor natural environments, with some cases dedicating the majority of children's school time to such settings.

The more recent concept of "green schools" emerged in response to the sustainability challenge and global concerns about growth limits, stemming from the Our Common Future Report (Brundtland, 1987) and the first United Nations Earth Summit in Rio de Janeiro (1992). New educational models started addressing the need to raise awareness among new generations and involve them in responding to socio-ecological and environmental crises (Iwan and Rao, 2017; Gough et al., 2020). According to the literature, we use the term "green schools" to refer precisely to all derived educational experiences and models that explicitly promote environmental education and sustainable development. This global phenomenon includes programs like "Enviroschools," "Sustainable Schools," "ResourceSmart Schools," and the widely diffused "Eco-Schools," promoted by the Foundation for Environmental Education (FEE) and operational in 77 countries and over 59,000 schools (Plevyak, 2022). While green schools share

guiding principles indicative of a transnational sustainability culture, the methods, content focus (whether on environmentalism, ecology, or general sustainability), and the extent to which these principles are applied vary based on specific contexts.

Comprehensive reviewing of the worldwide spread and maturity of 'green schools' is challenging. Yet, contributions, including surveys by Montazami et al. (2015), Iwan and Rao (2017), Park and Lee (2019), and Gough et al. (2020), provide insights into the international matrix and diverse local implementations. Key innovations in green schools encompass integrating environmental subjects into curricula, conducting outdoor activities and sessions, providing gardens and outdoor green spaces, involving the school community in monitoring energy, water, and food consumption, and committing to recycling, energy saving, and rainwater recovery (Gamarra et al., 2018).

Regarding the school physical environment, while "forest schools" mainly focus on outdoor spaces, the "green school" approach emphasizes the technical aspects of sustainable design. Such environmentally sustainable solutions involve materials with low ecological footprints, minimal indoor CO2 emissions, reduced fossil energy use for management, heating, and cooling in favor of renewables, and improved passive ventilation and natural lighting. Sustainable school design often employs life-cycle assessment, certification, and efficiency achievements. It is no accident that the Center for Green School, established in 2000 and actively promoting certification and awards for sustainable schools, is part of the United States Green Building Council (USGBC), that is also responsible for creating the globally recognized building sustainability certification system called Leadership in Energy and Environmental Design (LEED).

The technical perspective sees schools as catalysts for reducing environmental footprints, raising awareness about daily life impacts, and promoting sustainable behaviors (Cole and Altenburger, 2019; Cole and Hamilton, 2020). However, this approach does not necessarily integrate nature into the educational space.

In terms of nature-design synergy in schools, the "biophilic design" framework provides a compelling approach that is rooted in the 'biophilia hypothesis' (see above). This approach addresses the human innate biophilic predisposition by incorporating nature into both indoor and outdoor spaces, primarily through enhancing perceptual connections with plants and other natural elements. This involves enhancing perceptual connections with plants and other natural elements through design components like forms, materials, lighting, and acoustics. Biophilic design aims to create a beneficial environment, utilizing principles of direct, indirect, and symbolic experiences of nature. It intervenes in the relationship between indoor and outdoor spaces and between artificial and natural elements, including vegetation, light, air, views, materials, finishes, and colors (Browning et al., 2014; Bolten and Barbiero, 2020).

Biophilic design principles, which have also been elaborated for childhood educational facilities (Park and Lee, 2019), can be summarized as engaging with nature in space, introducing it through form imitation, materials, colors, and sensory cues, and reimagining features inherent to natural settings, including visual permeability, observation points, refuges, and a sense of protection (Kellert, 2008, 2018; Browning et al., 2014). Biophilic design, grounded in scientific evidence and empirical knowledge, directly considers the link between well-being and nature contact, adopting a human-conscious perspective. It represents a promising method for possible synergies with more nature-oriented pedagogies, emphasizing the need for analyzing biophilic school projects.

1.4 Framing the research and its goals

This paper presents results from the intersection of interdisciplinary expertise, primarily environmental sociology and design. The research focuses on learning environments, given the urgency illustrated in Section 1.2 of re-naturalizing the built environment and the potential role that schools can play in this process.

Our main research goal is to contribute to the advancement of a field of study where design and education knowledge mutually cooperate for the re-naturalization of education spaces. Specifically, our research aims to overcome some of the limitations that affect design practice in its attempt to introduce sustainability and nature experience in schools. These limitations are often rooted in some of the constraints and gaps of existing research in this field.

First of all, sustainable technical precepts and biophilic design principles should be seen as complementary in an integrated approach to green school spaces. Indeed, to address the proven impact of nature on well-being, school design must encompass both environmental sustainability, focusing on technical and energy aspects, and the challenges of creating comfortable and human-conscious spaces. However, while the technical approach is extensively covered in green school literature (e.g., Della Torre et al., 2020), biophilic design has been understudied thus far. Spatial considerations and acknowledgment of biophilic theory are lacking in green school literature. The people-plant relationship is mainly explored in terms of educational programs, with architectural enhancements often discussed in relation to technical adjustments, energy conservation, and waste reduction (Gough et al., 2020). Moreover, it is noteworthy that the operationalization of the biophilia concept is not consistent across all projects that make reference to it. Numerous school projects, including award-winning architectural designs like Meadowbank Schools in Sydney, New Zealand, or the Wondering School in Almere, Netherlands, are often labeled as "biophilic schools." However, the degree of nature integration in the design and function of school spaces can vary significantly, and some projects may exhibit inherent contradictions in their actual construction's ecological footprint. Therefore, our research aims at contributing to a comprehensive analysis of biophilic schools that is imperative to avoid oversimplification of biophilia to mere inspiration or a branding label.

Analyzing biophilic design in educational spaces is also crucial to pinpoint the most effective relationships between school architecture, pedagogy, and nature. Despite the increasing number of schools designed with these goals, there are unexplored implications and potential paths for incorporating plants into learning environments. The growing awareness of nature's benefits in education is renewing the dialogue between pedagogy and architecture concerning the role of school spaces (Duthilleul et al., 2021). In the past decade, research has shifted from examining *if* school settings impact learning to investigating *how* the physical and material structures of educational spaces influence teaching and learning experiences. This research has established a connection between the nature of educational space and the activities that take place there (*ibidem*, p. 13). This body of

ongoing research addresses Weinstein's conclusion that "the relationship between physical design and educational program has been relatively neglected by educational researchers [..and..] research is needed to explore and document the ways in which physical factors and instructional programs interact, and to develop research-based guidelines for those engaged in creating educational settings" (Weinstein, 1979, pp. 599–600). Therefore, acknowledging nature's positive impact on learning and well-being, this paper explores the relationships between different approaches to school design and educational models, discussing a series of promising directions of collaboration that incorporate the latest research findings on the relationship between plants, health, and well-being, that have been highlighted above (see Section 1.1).

By doing so, our research aims to address the lack of systematic, interdisciplinary analyses on the outcomes of biophilic design solutions, proposing a set of theoretical concepts that serve as analytical tools that we believe can help in the analysis and evaluation of green schools, avoiding an oversimplistic and instrumental adoption of biophilic design principles.

2 Materials and methods

The study leverages the background analysis outlined in Section 1, that showed the limitations of the analytical perspectives that have studied green schools so far. To do so, the study follows an exploratory approach, based on the analysis of case studies.

The aforementioned promising directions of collaboration between design and pedagogical disciplines are illustrated through the analysis of three examples of schools, in America, Asia, and Europe. These case studies were selected through a literature review on green schools (e.g., Montazami et al., 2015; Iwan and Rao, 2017; Park and Lee, 2019; Gough et al., 2020), because they exemplify strategies promoting environmental sustainability and well-being through the incorporation of nature and plants in school settings. These cases serve to demonstrate how the people-plants connection is achieved through varied combinations of design choices and educational paradigms. Specifically, these cases illustrate a variety of relationships between plants and architecture that are implemented through choices that recall the biophilic design approach. Examining the selected projects and their unique stories and contexts reveals distinct synergies among architecture, plants, and pedagogical models.

After a preliminary analysis of the cases in Section 3, these cases will be discussed in Section 4 adopting an analytical framework that can be useful for future analysis of the design and pedagogical choices in this field and, more in general, of the re-naturalizing efforts of the built environment in different contexts. This analytical framework refers, on the one hand, to the *promoting roles* for school re-naturalization played by design and educational paradigms. On the other hand, the case study will be discussed adopting a *theoretical framework on plants-architecture relationship* that works as a further analytical tool to illustrate how the principles of biophilic design can be implemented in different contexts. This theoretical framework—one of the original contributions of this work—had been previously developed by one of the authors by analyzing the relationship that historically architecture and design have held with natural elements and, specifically, with plants.

3 Case studies analysis

The analysis of the three selected cases of this Section follows a similar structure for each case. After describing the geographical and cultural context, the analysis illustrates the process of ideation, the philosophy and the main principles that influenced its design project. Specifically, the analysis focuses on the relationship between the physical spaces of the school and the natural elements it includes, and on how this relationship is connected to the pedagogical approach that is adopted in the school. As anticipated, these aspects will be extensively discussed in Section 4.

3.1 Biophilic design as an alternative to fortification in an American school

Sandy Hook Elementary School is located just outside Newtown, a 30,000 residents town in Connecticut, U.S. This school serves as a North American case study illustrating an innovative connection between architecture, plants, and pedagogical models. Inaugurated in 2016, the school gained attention for replacing the previous building, the site of the most severe school massacre in U.S. history in December 2012. This tragic event led to the deaths of twenty children and six educators at the hands of a former student in his twenties with mental health disorders.

The Newtown events and the new school construction are contextualized within the U.S. legislative and public debate framework on gun ownership. The highly polarized gun ownership debate influences strategies addressing firearm-related incidents in U.S. schools. Incidents numbered a few dozen annually until 2017, with occasional peaks of around 50–60 cases. However, an exponential increase in recent years raised the number to more than 300 cases in 2023 (see the Center for Homeland Defense and Security, CHDS[1]).

In a context where restricting widespread access to firearms is hindered, common response strategies center around the concept of 'target hardening' (Jonson, 2017). This involves fortifying school buildings, increasing armed surveillance, utilizing closed-circuit cameras, and developing safety and evacuation protocols for students and teachers (Burton et al., 2021).

In contrast, the new Sandy Hook School's story stands as a testimony to an alternative approach, where the integration of nature becomes a cornerstone, deviating from the dominant strategy of escalating security measures. The fact that the State government funded the entire process, from demolition to design and construction of the new school, with 50 million dollars underscores its significance in the North American context.

Newtown's innovative strategy is closely tied to the process of conceptualizing and building the new school. Firstly, the decision to swiftly demolish the old building and construct a new one in the same location was a crucial step in the collective grieving process for the local community.

Secondly, the winning project, meeting stringent security requirements, actively engaged the community through a participatory design process. This aimed to restore a deep sense of community and

1 https://www.chds.us/sssc/

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the school's role in the daily lives of its inhabitants. After extensive listening sessions with Newtown residents and workshops involving the school community, including kindergarten and primary students, the Svigals+Partners firm designed and built the school with strong allusions to the local natural landscape.

The design's key elements emerged from the participatory process, incorporating clear references to surrounding natural features. These include a curvilinear and undulating façade reminiscent of Newtown's hilly landscape, bridges resembling those over the town's river, and the extensive use of wood in both interior and exterior elements. Stylized natural elements within the interiors, symbolizing trees, leaves, and animals, frequently referenced by the children, further contribute to the design (Figure 1).

The new Sandy Hook School strongly promotes the connection with nature through explicit adoption of biophilic design principles (see Section 1.3). The participation as consultant on the project of the ecologist (Kellert, 2018), theorist of the biophilia hypothesis (Kellert and Wilson, 1993), facilitated this approach. The previous squared layout was replaced with a comb-shaped design, enhancing views from classrooms through large glass windows. This design maximizes panoramic perspectives of the surrounding natural landscape, gardens, and courtyards.

Explicitly encouraging a connection with nature aims to enhance psychological well-being, a fundamental requirement for fostering a healthier community and mitigating distress's underlying causes, including the prevention of severe outcomes like gun violence (Latane, 2021).

Design elements reflecting the biophilic approach include the concave façade conveying a welcoming atmosphere, gardens and courtyards irrigated with rainwater from parking lot rain gardens, blending biophilic design with environmental awareness, an amphitheater in one of the outdoor gardens, and multi-functional spaces with large glass volumes facilitating movement and group dynamics. Additionally, smaller spaces, termed 'treehouses,' facing the landscape encourage intimate interactions or solitary introspection inspired by nature's views (Figure 1).

Providing spatial features and incorporating activities like horticultural therapy into the curriculum, the Sandy Hook School

FIGURE 1
Sandy Hook School, by Svigals+Partners (Newtown, CT, USA, 2017). The biophilic design approach adopted for the reconstruction of the building after the 2012 massacre leverages a pervasive connection with nature as a tool for community reconciliation with the school. The natural environment is consistently referenced in the interiors through materials, forms, and colors. Large windows allow for natural illumination, visually connecting with the external landscape and gardens nestled among the classroom's structures. **(A)** The entrance facade with visual references to the landscape. **(B)** A hall and social space, with decorations and references to natural elements, and the view to the garden. **(C)** One of the gardens serving the classrooms with, on the right, the "treehouse" seen from outside. **(D)** A diagram of spaces distribution. (Courtesy of: photo A © Robert Benson; photos B and C © Svigals+Partners).

aligns with the principles of Therapeutic Landscape Design (Marcus and Sachs, 2014; Capolongo et al., 2023), where nature fosters a serene relationship with the school environment, transforming it into a well-being space and enhancing the overall school experience.

By integrating advanced security measures like bulletproof glass and stringent access control, this project innovatively advances the Crime Prevention Through Environmental Design (CPTED) approach, explicitly mentioned in project documents. Despite adopting 'embedded security' and 'natural surveillance' principles, the visibility of security devices is minimized. Security and prevention are indirectly ensured through spatial organization and design solutions prioritizing the fulfillment of the biophilic approach and the defined pedagogical goals of the school project. For instance, views are strategically arranged for enjoying the natural landscape while monitoring external threats, harmoniously integrating biophilic and security design.

Therefore, this project signifies a notable shift in the relationship between designed space and security, challenging the prevailing emphasis on closure. Departing from the standard approach where security governs spatial design, this project subordinates security to maximizing the relationship with nature, that becomes the central axis shaping learning experiences and, more broadly, habitation.

3.2 The natural environment as a three-dimensional textbook in an Asian school

The second case study, an Asian one, is the Green School in Bali, operational since 2008 on the rural outskirts of Denpasar, Indonesia's capital. Its founders, John and Cynthia Hardy, a North American couple with a background in design and jewelry production in Bali, divested their business in 2006 due to their environmental concerns and developed an educational campus fostering a close connection with nature to promote environmental and social sustainability.

Designed by Ibuku studio, this school campus is globally recognized as one of the most exemplary green schools. It earned the title of 'Greenest School on Earth' in the USGBC's inaugural award in 2012. Due to its international prominence and the founders' compelling communication abilities, the Green School in Bali is often acknowledged as one of the most sustainable and innovative institutions worldwide (see, Plevyak, 2022, or the World Economic Forum's 'Schools of the Future' report, World Economic Forum, 2020).

Over the years, numerous studies have scrutinized the Green School from various angles, exploring its spatial characteristics, educational model, and, particularly, the relationship between the efficacy of the pedagogical model and the architectural and environmental features of the campus (Hazzard and Hazzard, 2012; Kong et al., 2014; Iwan and Rao, 2017; Alimin et al., 2021).

The campus is situated in the Balinese forest, and its numerous structures, including the river-access bridge, are primarily constructed from natural materials, notably bamboo. This indigenous plant, emblematic of local vernacular architecture, is chosen for its minimal environmental impact, structural reliability, and construction capabilities (Jayanetti and Follett, 1998; Correal, 2019).

The research findings demonstrate that the forms, articulation, and substantial dimensions of the Balinese school's buildings—where bamboo culms are intentionally exposed (Figure 2)—provide not just aesthetic value but also carry symbolic significance. Campus attendees perceive this design choice as emblematic of the alignment between ecologically aware teachings and the spaces where they are implemented. Additionally, owing to the favorable local climate, most campus buildings are openly connected to the outdoors, fostering continuous interaction with nature.

In an environment where students maintain an ongoing relationship with the natural surroundings, nature is not just a framework for school activities; instead, it often becomes the primary subject of the educational curriculum. The Green School in Bali adopts a teaching model where only a few core subjects are conducted within classrooms, and most other disciplines, including natural sciences, environment, art, and creativity, are experientially approached outdoors. Consequently, the architectural design, natural spaces, and sustainable infrastructures of the campus, such as solar and hydroelectric systems for energy production and waste management, become direct objects of study for students to experience and evaluate for efficacy. Compostable toilets and the Bio Bus, utilizing used cooking oil for student transportation, are two examples of devices developed through student experiments and investigations.

The school serves as a "three-dimensional textbook" for environmental education (Taylor, 1993; Kong et al., 2014). Its ever-evolving spaces inspire a similar approach in addressing various contexts and issues, fostering reinterpretation with innovative and sustainable perspectives. As per Alimin et al. (2021) findings, this profoundly shapes the values, daily behaviors, and lifestyles of both students and the wider community associated with the school. An illustrative example is a campaign initiated by two 12 and 14-year-old students that successfully advocated for the prohibition of plastic bags in Bali, highlighting numerous student-led projects promoting social and ecological causes.

The Green School in Bali has a distinct international focus, aspiring to nurture future leaders with a commitment to environmental sustainability values. With annual tuition fees ranging from €7,000 to €17,000, the school attracts students from the global community with significant financial resources residing in Bali. Families are required to align with the school's environmental and social principles, whose fame is renowned beyond the island. Occasionally, international students are accompanied by their families, who temporarily move to its adjacent rural area.

The Green School in Bali maintains a crucial connection with the local community, which has a lower average income than international students. 10–20% of the enrollment is offered through a fully funded scholarship program for Balinese students. Additionally, most student projects and social campaigns focus on involving the local community to improve its conditions.

3.3 A new model for the re-naturalization of schools in the European urban context

The third case study is situated in an urban European setting. Colegio Reggio is a Madrid-based private school in Spain catering to students up to the age of 18, drawing inspiration from the educational principles of the Reggio Emilia Approach (REA).

REA, an educational philosophy emerging in Reggio Emilia, Italy, post-World War II, centers on early childhood education (0–6 years). Initiated by the local community under Loris Malaguzzi's guidance, it embraces principles such as collaborative staff work; the daily presence of multiple educators and teachers; the *ateliers,* i.e., workshops for artistic expression, and the figure of "atelierist" aiding and supporting children in creative activities; the use of an internal kitchen for taste

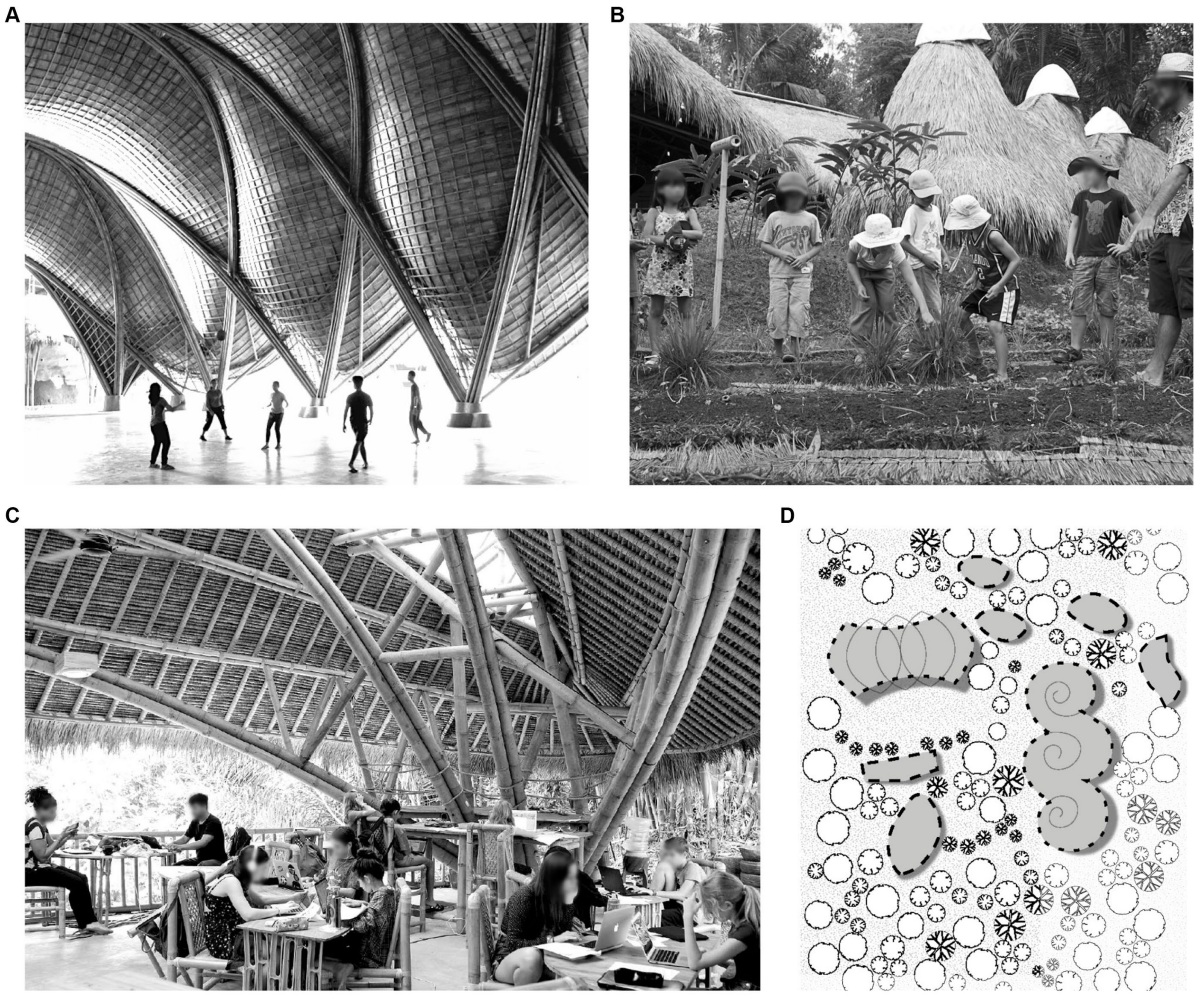

FIGURE 2
Green School, by IBUKU (Bali, Indonesia, 2006). The Bali campus embraces local bamboo construction traditions, integrating them with the regional residential culture. Educational activities occur in built spaces (classrooms, social spaces, and facilities such as the gym, the cafeteria, and the theater), that are distributed within dense and permeable vegetation, as well as in *en-plein-air* spaces integrated into the greenery, such as the large lawn or the educational garden. The diagram **(D)** encapsulates this synergy, depicting a unified educational space where indoor and outdoor environments seamlessly coexist within lush, permeable vegetation. **(A)** The iconic and versatile space called "the Arc." **(B,C)** Indoor and outdoor educational activities. **(D)** A diagram of spaces distribution. (Courtesy of: photo A © Tommaso Riva; photos B and C © Green School Bali).

workshops; the pedagogical role of the environment, that is considered as an educator; documentation to visualize learning processes; coordination of pedagogical aspects; and family participation. Currently, the principles of the Reggio Emilia Approach are disseminated globally through a network of schools inspired by this method, continuing the research and civic commitment initiated in Italy (see, e.g., Edwards et al., 2014; and the official REA website, www.reggiochildren.it/reggio-emilia-approach/).

In 2017, Colegio Reggio selected Andrés Jacque and his architectural firm, Office for Political Innovation (OPI), to design a new campus, inaugurated in 2022. Unlike previous case studies, it has not yet undergone post-occupancy evaluations. Despite this, due to its distinctive attributes, this case study is a valuable example for understanding the evolution of the green school phenomenon and suggesting fruitful directions for the future.

Colegio Reggio's new campus merges the pedagogical principles of REA, emphasizing the active educational role of space, with OPI's social and ecological sensitivity. The school functions as an ecosystem, where the interplay of architecture and natural elements encourages an autonomous educational process and collective experimentation, nurturing students' personal inclinations and celebrating diversity.

The school is located in the recently developed Encinar de los Reyes residential district in Madrid. The building faces an open lot to the north, creating distance from the road and urban areas, while to the south, it opens spatially and perceptually to the public park of El Encinar Sur and the area of the Valdebebas creek. The school building, spanning five floors, features central areas on each floor designed alternately as social spaces or, on upper floors, as indoor woodlands with diverse tree species and ample natural light—crucial for plants (Figure 3).

Educational spaces vary on each floor based on students' ages, providing diverse interactions with natural elements. The first floor, for nursery students, offers direct contact with earth and vegetation. Upper floors group students by age, offering indoor gardens with various botanical species. The third floor's indoor woodland has tall trees reaching upper-floor balconies. The highest floor's classrooms, arranged like a small village around vegetation, cater to older students, providing spatial opportunities for increasingly autonomous exploration of the school's ecosystem. In summary, spatial and

FIGURE 3
Colegio Reggio, by Office for Political Innovation (Madrid, Spain, 2022). In Colegio Reggio the integration of nature and pedagogical principles is achieved through the incorporation of a small indoor forest and the application of the educational approach of the Reggio Emilia School. The building's levels are designed to provide different opportunities for interaction with natural elements, tailored to the students' ages. Lower levels prioritize connections with roots, water, and earth, emphasizing principles of care and nurturing. Starting from the third level, classrooms overlook plants and trees, becoming central to pathways and different activities. Facades, designed to accommodate additional vegetation, selectively filter the visual relationship with elements of the surrounding natural and urban landscape. **(A)** The external facade with the porthole windows. **(B)** The visual integration of nature in a ground-floor classroom. **(C)** A view on the indoor forest. **(D)** A diagram of spaces distribution. (Courtesy of: photos A and C © Leonardo Chiesi; photo B © Office for Political Innovation).

environmental distinctions at different levels aim to stimulate students in various developmental phases, employing functional, aesthetic, and symbolic solutions to encourage exploration, autonomous learning, and interaction with people and the surrounding environment (Strong-Wilson and Ellis, 2007; Fraser, 2012). Thus, plants are an integral part of the school environment, influencing shared spaces beyond classrooms, such as the second-level gymnasium or the third level with its central woodland. These areas serve as hubs for social interaction, nature experiences, and *atelier* activities[2].

The project aligns natural elements, spatial attributes, scholastic organization, and REA principles, synergistically enhancing the pedagogical role ascribed by REA to space as a 'third teacher.' The project facilitates exploration of natural elements, supporting a key REA principle that perceives the child as a 'capable and conscious' individual, capable of forming independent relationships with their physical and social environment and embarking on a path of autonomous learning through personal exploration (Edwards et al., 2014). Students can interact with plants comprehensively, from roots to canopy, experiencing water, soil, light, and the dynamics of growth and care within the intricate ecosystem of nature. Thus, they have the opportunity to learn from both the natural and the built environment in a harmonious and integrated space.

The visibility of the plant nourishment systems and technological management of the building promotes resource-conscious awareness and facilitates the diffusion of ecological sensitivity This aligns with another REA principle: the active involvement of families in school life. Families are designated by the REA as the 'second teacher,' alongside educators and the environment, and contribute significantly to student development.

This open micro-ecosystem provides daily interaction, showcasing nature's functioning and equilibrium, offering an opportunity to disseminate ecological culture within the school community and, consequently, into the urban setting.

2 Ateliers, integral to the Reggio Emilia Approach (REA), are workshops for artistic expression encouraging children to observe and express themselves, highlighting diversity and motivating individual inclinations.

4 Results and discussion

The three selected schools can be used as cases to exemplify various aspects of the interplay between design, educational models, and nature. First, the cases will be discussed highlighting the different roles played by design and the pedagogical models in the promotion of the re-naturalization of spaces (Section 4.1). Then, the discussion will focus on how such results can be achieved adopting different design strategies, that refer directly or indirectly to biophilic design principles. To further clarify such strategies, a theoretical framework of dynamics that plants and nature have historically played in architecture will be first introduced (Section 4.2) and then applied to analyze the three case studies (Section 4.3).

4.1 Design and pedagogical models in the promotion of school re-naturalization

The three case studies illustrate diverse interactions between architecture and pedagogical models, outlining distinct pathways for incorporating a more prominent presence of nature, particularly plants, within educational environments.

In some instances, architecture plays a pivotal role in facilitating increased interaction with nature within school environments. A notable example is the new Sandy Hook school, where the design competition did not explicitly prioritize reconnecting with nature. Nevertheless, the biophilic approach introduced by the winning design team, contributes in diverging from the prevalent inward-focused 'target hardening' trend, which typically limits interactions with the surrounding natural environment. The design incorporated references to the local natural landscape for its symbolic significance to the community. Therefore, in the Sandy Hook case, it is the design that initiated a positive reconnection with nature, subsequently influencing the pedagogical approach. The space for nature and nature-centered activities in the educational program was an effect of the opportunities offered by the new design of the school. Once embraced, this connection with nature served as a creative tool, enhancing the well-being of the school community, and avoiding the drawbacks of rigid security-focused design models.

In other cases, the emphasis on a substantial presence of nature in pedagogical models guides spatial considerations. The Green School in Bali serves as a prominent example where the school's educational model and values significantly impact spatial and design decisions. This influence is evident in the strategic selection of a favorable rural setting, the integration of spaces and buildings with the natural surroundings, and the deliberate use of bamboo as the primary building material, carrying functional, symbolic, and environmental significance. In cases like the Green School in Bali, these options thrive due to favorable environmental conditions. However, in urban settings, enhancing the connection with nature presents a formidable challenge, necessitating a robust collaboration between advocates of innovative pedagogical and architectural approaches.

Colegio Reggio exemplifies this synergy where ecological awareness is embraced by both the proponents of the pedagogical model and the design firm shaping its spatial layout. In this instance, the educational role attributed to space by the Reggio Emilia Approach as a 'third teacher' harmonizes with the environmental sensitivity embedded in the school's design. This convergence creates conditions for students and the entire school community to deeply engage with plants and their natural features, facilitated by both the spatial and educational environment.

4.2 Biophilic design and plants–architecture relationship

Given the pivotal role of design choices in the re-naturalization of the school environment and overall community experience, exploring variations in these choices is valuable. Different pedagogical objectives and diverse social-cultural contexts employ various strategies and techniques to integrate nature into inhabited spaces.

Understanding these distinct strategies and their perspectives toward nature is crucial for analyzing the spectrum of biophilic-inspired projects. To facilitate this analysis, contributing insights, we decided to contextualize current design practices within the trajectory of plant-architecture historical relationship, employing a theoretical framework that we propose. According to this framework, the connection between plants and architecture follows a cyclical pattern. Over varying temporal scales, architecture first eliminates plants, emerging from their removal. Subsequently, plants reappear through modes of *inspiration*, both formal and structural, and *integration*. Finally, architecture possibly permits plants to take center stage, transforming into architecture themselves. This dynamic *substitution* results in profound hybrids, blurring the distinctions between architecture and plants and challenging the prevailing notion of the "built."

Examining these phases in more detail, construction inherently involves displacing plants from the occupied space. The act of building requires available space, typically inhabited by plants. This initial displacement seems inevitable, arising from a human-nature conflict where humans assert control. As Ingersoll notes (Ingersoll, 2012, p. 254), "every act of building betrays the environment, as it requires the displacement of 'natural' relationships." Nonetheless, if humans relinquish control, plants reclaim the space, setting up an irreducible opposition between plants and architecture[3].

Excluded from the built environment, plants reemerge as abstract *inspirations* for architecture. They serve as semantic inspiration, acting for example as templates for historical ornament catalogs adorning building exteriors and interiors. Simultaneously, the observation and imitation of plants inspire solutions to construction and structural challenges, fostering innovative ideas for stability, resilience, and efficiency[4].

3 Historically, this opposition echoes in accounts of rituals dispossessing vegetation during settlement in ancient cultures (Rykwert, 1976). Even today, architectural guidelines acknowledge this incompatibility, providing advice on issues like maintaining a safe distance between structures and trees to avoid stability issues, or addressing challenges related to water presence in buildings (crucial for plants yet hazardous for structures).

4 Plant-inspired solutions range from elementary columns imitating tree trunks to intricate weavings, like Joseph Paxton's Crystal Palace (London, 1851), inspired by the rib structure of the giant leaf of Victoria amazonica. Another example is the creation of flexible joints, inspired by bamboo plants, maximizing anti-seismic characteristics in the Taipei 101 (Taipei, 2004), one of the world's tallest buildings.

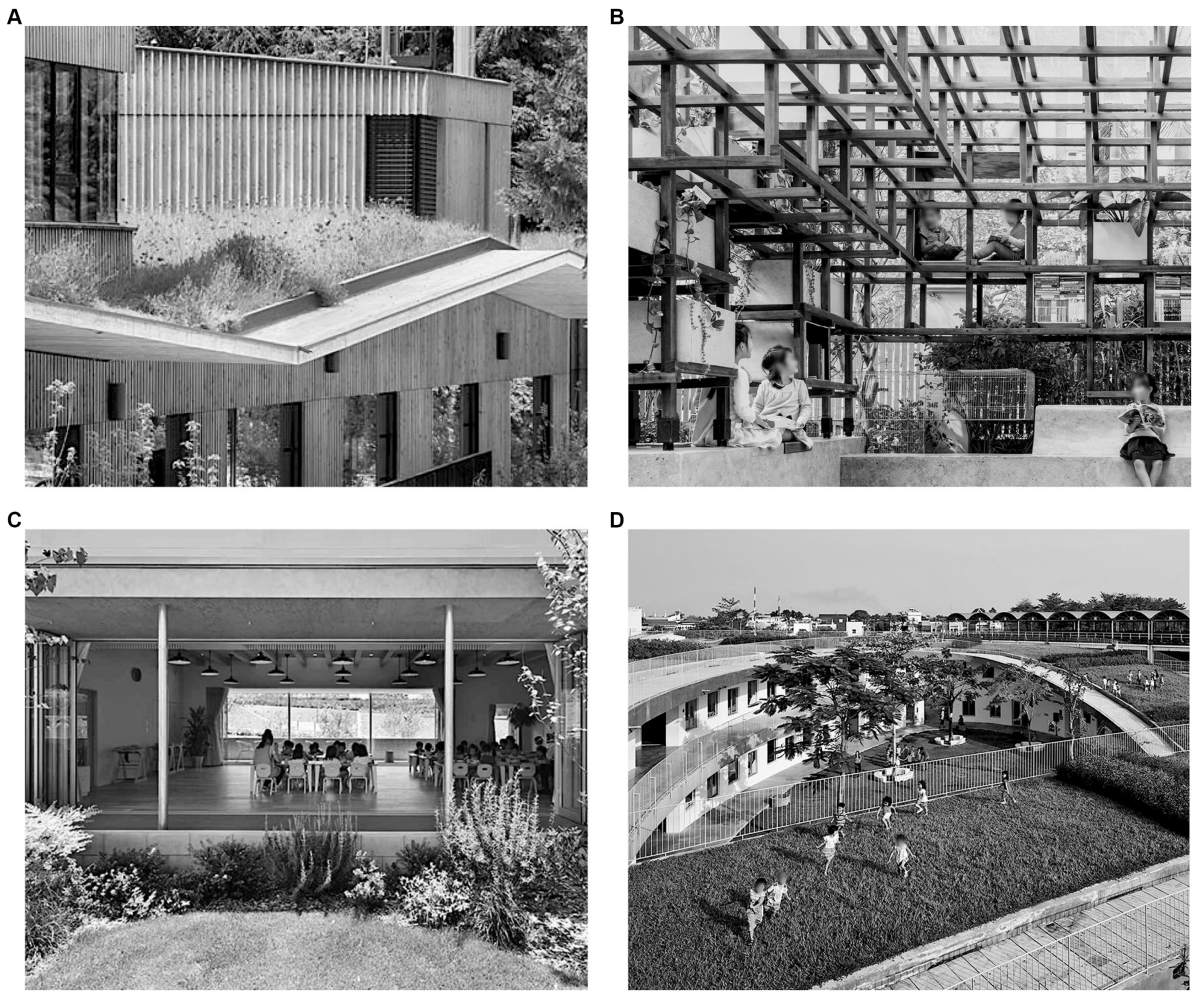

FIGURE 4
Four examples of biophilic schools. **(A)** *Paul Chevallier school complex*, by Tectoniques (Rillieux-la-Pape, France, 2013). **(B)** *VAC Library* by Farming Architects (Hanoi, Vietnam, 2018). **(C)** *SM Nursery* by Hibinosekkei + Youji no Shiro (Tokyo, Japan, 2015). **(D)** *Farming Kindergarten* by Vo Trong Nghia (Dong Nai, Vietnam, 2013). Sustainability culture and biophilic design are common features in schools seeking to enhance their connection with nature. These principles take on different forms depending on the climate, local culture, and teaching methods. The design of schools may draw inspiration from natural elements by **(A)** reflecting the surrounding landscape or **(B)** replicating spatial features like richly articulated spaces. Alternatively, schools can integrate nature to **(C)** enhance visual and perceptual enjoyment or **(D)** allow for direct immersion. (Courtesy of: photo A © Renaud Araud; B © Thai Thatch & Viet Dung; C © Studio Bauhaus; D © Hiroyuki Oki).

In the subsequent phases, plants re-enter the built environment in controlled ways, following formal rules. Urban city gardens exemplify this controlled *integration* at an urban scale, representing managed nature in contrast to the wild nature outside cities, like forests and jungles. This integration also occurs within individual structures, occasionally leading to hybrids with pervasive plant presence[5].

Lastly, living plants, shaped with patience to follow their growth cycles, can *substitute* for traditional architecture, producing structures that replace conventional construction[6]. This stage completes the cycle, coinciding with the original state where plants dominate space.

According to the discussed theoretical framework, biophilic design responds to the exclusion of nature by drawing on inspiration and integration of plants into architectural designs, particularly within educational settings. Indeed, biophilic architectures can exhibit distinctive and recognizable forms, clearly *inspired* by nature and plants. For instance, the Paul Chevallier school complex in Rillieux-la-Pape (Lyon, France, Figure 4A) features a prominent cantilevered roof with an undulating profile, creating a rooftop

5 Examples include the fifth-century BC Palace of Nineveh (likely the origin of the Hanging Gardens of Babylon legend, see Dalley, 2013), as well as contemporary tropicalist projects (e.g., Oscar Niemeyer's works in Brazil and Vo Trong Nghia's in Vietnam), and avant-garde endeavors by Friedensreich Hundertwasser or Gianni Pettena. These architectures engage in close dialogue with plants, often constructing buildings around pre-existing trees, challenging implicit assumptions of the dominant design culture regarding the boundary between the built and the vegetal.

6 In tropical Indochina, bridges were historically crafted using guided living vines and roots, forming robust and elastic spans. This historical precedent anticipates contemporary design trends where some architects explore architecture evolving from construction to organic vegetal growth (e.g., Kuma Kengo, Birch and Moss Chapel, Karuizawa, Japan, 2015; Xu Chaoran, Bamboo Theater, Hengkeng, China, 2015; Baubotanik's multi-storey structures with living plants).

garden accessible via a short pathway. The roof, which seems to be made of the grass and flowers that blanket it, mimics the natural slopes of the surrounding landscape and is visible from the inside through large classroom windows. Additionally, the diverse perspectives, volumetric design, and profiles, coupled with the exclusive use of wood for internal finishes (floors, walls, and ceilings), consistently evoke nature in the architecture. This dominant aspect of the project pays homage to and maintains continuity with the pre-existing natural landscape.

Elsewhere, nature-inspired design replicates its spatial characteristics, including niches, shelters, spatial complexity, diverse perspectives, and privileged observation points. In the VAC Library in Hanoi (Figure 4B), these features dominate the relationship between nature and architecture in a structure designed for children. Architecturally, the project involves permeable modules—a dynamic composition of niches, volumes, solid and void spaces housing plant pots, chicken cages, and aquaponic systems with fish tanks and aquatic plant cultivation. The open-air library, designed as a miniature ecosystem, serves as an educational space for understanding ecosystem dynamics. Here, children are encouraged to play, read, and creatively engage with the environment independently, finding shelter in niches, climbing structures, and observing their surroundings.

Continuing the analogy with the modes of interaction between plants and architecture, biophilic design involves the *integration* of plants into educational spaces. Initially, this integration is visual and perceptual. The SM Nursery in Tokyo (Figure 4C) exemplifies this, combining biophilic principles and pedagogical sensitivity in a school space designed to offer open nature experiences through multisensory stimuli and varied visual perspectives. The structure comprises two V-shaped blocks, enveloping an open green area with diverse plant species, a water basin, a garden, a panoramic walkway-*cum*-porch, and a climbing structure. The use of entirely removable windows and intermediate loggias establishes visual and perceptual permeability to nature, fostering a seamless connection between the indoor and outdoor environments.

In other cases, nature integration allows a direct, even pervasive, experience of nature, incorporating plants into daily activities. For example, the Farming Kindergarten in Dong Nai, Vietnam (Figure 4D), where plants envelop the building, creating a suspended green walkable circuit on the roof for the children. The school consists of two sinuous two-story volumes topped with a garden-farm converging at the center, forming a knot-shaped ground level. The volume's dynamic design, green roofing, and expansive windows, establish perceptual continuity between the building and landscape. Pedagogically, children actively participate in garden care, and the curved forms encourage outdoor physical activities, emphasizing the central role of the people-nature relationship, including cultivation practices, in the children's experience[7].

Inspiration and integration with nature are often combined, particularly when allusions to nature and plants go beyond mere aesthetic references and form part of comprehensive strategies to minimize environmental impact[8], with the goal of fostering a true reconnection with nature.

4.3 Inspiration, integration and substitution in our case studies

Highlighting additional biophilic schools further exemplifies nature-architecture dynamics in the three analyzed case studies above. Inspiration primarily defines the design of the new Sandy Hook school, evident in the building's shape, particularly the façade reminiscent of the surrounding landscape, but even in the use of natural materials, predominantly wood, in both interiors and exteriors. Moreover, in Sandy Hook school abundant stylized natural elements symbolize trees, leaves, and animals in the interiors, while varied spaces, from large multifunctional areas to smaller niches like the 'treehouse,' provide diverse opportunities for natural-like experiences (see Figure 1). Finally, wide openings providing views of the surrounding natural environment, as well as other features of the buildings, align with a dynamic of integration of nature, although visual and perceptual.

In the case of the Green School in Bali, the profound integration with nature is brought to a heightened extent, transforming the natural environment into the primary setting for all school activities (see Figure 2). As observed, this integration is intricately tied to the pedagogical model: it not only provides an optimal context for achieving environmental educational goals, but also establishes the fundamental role of nature as a locus of learning. In this sense, the intensive inclusion of nature in the Green School's spatial configuration, borders on architectural *substitution*.

As anticipated, in Bali the profound connection with nature facilitated by its strong integration is undeniably supported by favorable climatic conditions and a rural context. Regarding climate, it's worth noting that the Green School has recently expanded to new campuses in New Zealand (2020) and South Africa (2021)[9], situated at latitudes requiring distinct design solutions compared to those applied in Bali. In the spaces of the South African campus, the integration of nature is primarily limited to visual and perceptual elements, complemented by features inspired by nature, including volumes with organic shapes arranged in non-geometric compositions. However, the rural settings of the new Green School campuses allow for replicating key aspects of the pedagogical approach from Bali, including outdoor activities, experiential teaching, shared

7 As emphasized by the architects, the Farming Kindergarten in Vietnam confronts two pertinent local challenges: the diminishing natural resources due to swift urbanization and the food supply challenges arising from climate change and the waning agricultural traditions. According to details available on the architecture studio's website (vtnarchitects.net/farming-kindergarten-pe178.html), the Farming Kindergarten project seeks to address these concerns by establishing a space that incorporates nature into the educational setting and concurrently advocates for agricultural practices and food sustainability.

8 In the aforementioned cases, a comparable commitment to sustainability is evident. For example, in the Farming Kindergarten, there's emphasis on sustainable water management and energy efficiency. Wastewater is recycled for irrigation and sanitation, and the kindergarten, situated in a tropical climate, foregoes mechanical cooling by employing cross-ventilation and benefiting from the thermal insulation of the green roof. These practices enhance the building's overall environmental sustainability, adhering to principles of energy efficiency and resource conservation.

9 Another campus will be operational in Mexico starting from 2025.

management of natural and energy resources, and direct food production. Thus, diverse environments do not seem to constrain the emphasis on the central relationship with nature, a primary goal of the school experience.

It is crucial to address situations beyond rural contexts, more distant from nature, or notably mineral in nature. In high-density urban areas, where challenges from the absence of nature are most prominent, strengthening the relationship between nature and learning spaces becomes particularly significant.

Combining various dynamics appears as a strategy to overcome urban issues, making the Colegio Reggio of Madrid a noteworthy example of nature integration in the urban context. Facilitated by the synergy of the pedagogical model and design efforts, this Spanish school incorporates plants in both inspiration and integration modes. Plants serve as both a symbolic and spatial foundation for the structure of the learning experience, unfolding from roots and soil to the upper levels of tree foliage (see Figure 3). Simultaneously, bringing plants indoors and integrating them into the building ensures a direct experience of nature, thereby profoundly influencing the overall learning experience. In an urban context, Colegio Reggio's learning environment pioneers a novel model of urban and existential experience, indicating a path for re-thinking urban systems.

5 Conclusion

In this paper case studies were explored with the aim of demonstrating diverse trajectories in the relationship between nature and architecture, with a focus on learning spaces. Learning spaces play a crucial role in promoting environmental sustainability and strengthening the connection with nature in the population. Schools are dynamic and contextually responsive spaces, keenly attuned to their societal context. More than building typologies, they serve as architecturally sensitive environments, often revealing potential transformations.

The introductory section offered an overview on plant-health literature, presenting the context for the emergence of *forest* and *green schools*, outlining the specificities of pioneering experiences. It also explored the origins of the 'biophilia hypothesis' and its application in architecture, specifically 'biophilic design'. The subsequent analysis and discussion of three case studies (Sections 3 and 4), augmented by additional examples from various locations, exposed different paths in the relationship between architecture and pedagogical models under a re-naturalization perspective. It emphasized and compared diverse approaches to the influence of both architecture and pedagogical models in promoting the significance of nature in the learning and developmental experiences of students and the broader school community. Specifically, it was noted that in rural and peri-urban settings, more amenable to the reintegration of nature, this recovery could stem from the initiatives of either of the two involved domains—namely, architecture and pedagogical models—ultimately shaping the outcomes of the other. In urban environments, by contrast, a convergence of ecological sensitivities in pedagogical and design approaches could foster innovative solutions to surmount the challenges of reintroducing nature in such settings.

The paper also employed a theoretical framework outlining distinct phases in the interplay between plants and architecture, delineating a range of dynamics involved in the re-naturalization of spaces. This framework proves beneficial for discerning diverse strategies by which biophilic design can function across various contexts, particularly in educational settings. This specific purpose further emphasizes the selection of case studies. The schools discussed in this paper have not been selected with a random sampling strategy, and the characteristics of some of them—e.g., high building costs and tuition fees—do not allow to consider them neither as immediately replicable models, nor as representing an already accomplished and consolidated change in the path to re-naturalization of schools. This study exploratory and intentionally avoids aiming for a comprehensive and representative overview of plant-architecture interactions in learning spaces. Instead, the schools were chosen, on the one hand, for their ability to exemplify pioneering trajectories of some innovative design and pedagogical approaches that build on the re-naturalization of school spaces. On the other hand, they served to propose and test a set of analytical concepts that can be useful in the analysis and the evaluation of other re-naturalizing school models that, will continue to be emerge in the future.

This paper contributes to the green and biophilic schools' research field in multiple ways. Firstly, it suggests an interdisciplinary approach to address the gap between sociological and architectural literature dealing with nature-oriented educational programs and nature-based design projects. Secondly, it explores the dynamics through which biophilic design is adopted in educational buildings. The potential for biophilic schools to ensure quality education and a favorable environment for well-being during developmental stages has been acknowledged (Beatley and Newman, 2013; Zhong et al., 2022). However, the dynamics through which biophilic principles are integrated into educational spaces, programs and overall experience have remained largely unexplored. Currently, biophilic approach for schools is predominantly explored in terms of lists and classifications of existing design features and strategies (Beatley, 2011; Park and Lee, 2019; Zhong et al., 2022), while more recent works focus on outdoor applications (Russo and Andreucci, 2023). By discussing the pathways through which nature is incorporated into built spaces—via integration, inspiration, and substitution dynamics—and how this enhances educational practices aimed at the well-being of students and the school community, this paper advances knowledge on the biophilic approach for schools.

In the context of an increasing awareness of the urgent need for built environment re-naturalization, the analysis has demonstrated how educational spaces can serve as an insightful gauge of ongoing developments. As highlighted in the introduction, there is a demand for a more thorough exploration and systematic analysis of synergies between design, education, and nature in a greater number of cases. We believe that the proposed analytical framework can contribute to advancing this effort. On one hand, this framework can function as a tool to pinpoint the most effective and replicable solutions for re-naturalization. The proposed categories—namely, the promotional roles of pedagogical and design models, and the dynamics of the plant-architecture relationship—can serve as analytical tools to indicate the effectiveness of these solutions in specific contexts or in combination with particular pedagogical or

design principles. On the other hand, this analytical framework can mitigate the risk of overly enthusiastic celebrations of design endeavors where nature serves merely as an aesthetic reference, lacking the genuine capacity to influence the well-being of those inhabiting the built environment. It also helps avoid the use of nature as a marketing tool, akin to what is termed *greenwashing* in contemporary discourse. Further research is needed to validate this analytical framework, testing it on other cases of school re-naturalizations and to control its effectiveness in the analysis of other typologies of buildings and spaces, both public and private. Once this validation will have occurred, a more quantitative translation of the proposed analytical concepts is a desirable outcome of this research path.

This study also underscores the risk of separating the pursuit of schools' technological sustainability from the effort to naturalize the daily experiences of their inhabitants. As noted, the early green school buildings sought environmental sustainability in their structures and technological systems (e.g., low energy consumption, water and waste recycling, low carbon materials, and passive ventilation and heating systems). This objective aligns with globally recognized sustainability certification systems (e.g., LEED, BREEAM, WELL Building Standard). In many cases, the technological sustainability of schools may lack visibility and direct control by the school's inhabitants, who are not actively involved in meeting sustainability standards. However, aligning with the biophilia hypothesis, the absence of opportunities for the school community, especially students, to establish a direct or indirect connection with nature and other natural elements, like plants, reduces the likelihood of comprehensive understanding and adoption of sustainability practices in their daily behaviors and lifestyles. Therefore, while technological sustainability is necessary, it alone is insufficient for effective environmental sustainability diffusion. Achieving this goal requires combining technological sustainability with strategies resulting from joint efforts in architecture and pedagogical models to reintroduce nature into the learning environment.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Author contributions

LC: Writing – review & editing, Writing – original draft, Supervision, Conceptualization. PC: Writing – review & editing, Writing – original draft, Methodology. FC: Writing – review & editing, Writing – original draft, Visualization, Conceptualization. BG: Writing – review & editing, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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