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Integrating Sustainable Architecture Concepts in the Design of Nature-Based Elementary Schools

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ABSTRACT

The increasing urgency of environmental issues such as climate change has amplified the need for sustainability education, particularly at the elementary school level. This study explores the integration of sustainable architecture in the design of a nature-based elementary school located in Batam, Indonesia. The research aims to develop an environmentally responsive learning environment that supports both energy efficiency and active, experiential learning. A qualitative descriptive method was employed, involving site observation and documentation to assess environmental conditions, spatial needs, and design potentials. The proposed design incorporates key sustainable strategies, including passive solar orientation, natural lighting, cross-ventilation, and the use of eco-friendly materials such as bamboo and timber. Biophilic design elements—such as open-air classrooms, green courtyards, and educational gardens—are also integrated to enhance students' connection to nature and support cognitive and emotional development. The findings demonstrate that sustainable and nature-based architectural approaches can reduce energy consumption, improve indoor comfort, and serve as a medium for teaching environmental values. While the design shows strong potential, the study acknowledges limitations in terms of implementation feasibility and scope. Future research is encouraged to include post-occupancy evaluations and interdisciplinary collaboration to further advance sustainable educational environments.

Keyword: *sustainable architecture, nature-based school, energy-efficient design, biophilic design, environmental education*

1. INTRODUCTION

In recent decades, climate change and environmental degradation have become pressing global challenges [1]. One of the most effective mitigation strategies is to promote sustainability awareness and values through education, particularly from an early age. Schools, as the core institutions of formal education, play a strategic role in shaping the mindset and behavior of future generations regarding environmental responsibility [2].

The concept of nature-based schools has emerged as an innovative alternative to conventional educational systems by integrating direct interaction with natural environments into the learning process. This approach strengthens students' emotional and cognitive connections to nature, while also opening opportunities to implement architectural designs that are in harmony with the environment [3]. In this context, sustainable architecture serves as a critical foundation for creating healthy, energy-efficient, and ecologically responsible learning environments.

Several studies and real-world projects, such as the Green School in Bali and Sekolah Alam Depok, demonstrate how architectural designs that incorporate natural lighting, cross-ventilation, local materials, and open spatial configurations can successfully support both ecological sustainability and educational needs. Research by Modiano et al. [4] highlights the effectiveness of bamboo as a renewable local material that is both functional and aesthetically aligned with sustainable building principles. This material

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effectively reduces indoor temperatures, providing occupants with thermal comfort.

Moreover, the application of biophilic design in educational architecture has been shown to enhance users' mental health and overall well-being [5]. However, while the body of literature on sustainable architecture is growing, there remains a limited number of studies that specifically integrate sustainable architecture principles into the context of nature-based elementary schools in Indonesia, particularly in tropical urban environments with limited resources.

This study offers novelty by designing a nature-based elementary school that explicitly integrates sustainable and biophilic architectural principles, while considering the unique challenges and potentials of Batam City. The proposed design prioritizes energy efficiency and thermal comfort, while also merging educational, ecological, and social dimensions into a cohesive learning environment. This approach treats architecture not merely as a functional output but as an educational medium that fosters ecological awareness through consciously crafted spatial experiences.

Despite the growing discourse and practice surrounding sustainable educational architecture, there remains a significant gap in the comprehensive integration of sustainable architectural principles with nature-based learning methods at the elementary school level. Key research questions that arise include:

a) How can sustainable architectural principles be effectively applied in the design of nature-based elementary schools in tropical climates?
b) How can building design support active, nature-based learning while enhancing students' connection with the environment?
c) What are the technical and social challenges in designing sustainable schools in urban areas like Batam?

These questions highlight the need for a study that synthesizes architectural, ecological, and pedagogical considerations into an integrated design approach.

This study aims to explore and implement sustainable architectural principles in the design of a nature-based elementary school by developing a learning environment that supports outdoor, experiential education while promoting energy efficiency and environmental responsibility. In doing so, the research also seeks to generate adaptable design solutions that can serve as models for other educational institutions, particularly those located in tropical and urban settings.

2. LITERATURE REVIEW

2.1 Nature-Based School

Nature-based schools represent an alternative educational model that emphasizes direct interaction between students and the natural environment throughout the learning process. This concept is rooted in experiential learning approaches, where knowledge and skills are acquired through hands-on engagement with ecological systems. Unlike conventional schools that rely heavily on structured indoor instruction, nature-based schools center their pedagogy around outdoor activities, such as learning in gardens, forests, or natural open spaces [6].

The emergence of nature-based education in Indonesia is a response to the growing demand for a more contextual, holistic, and environmentally relevant educational system. It is believed that this model can significantly enhance students' environmental awareness and foster critical thinking and problem-solving abilities from an early age. Moreover, learning in natural settings provides multisensory experiences that are crucial to children's socio-emotional development and helps cultivate a stronger bond between students and the natural world [7].

Beyond its pedagogical benefits, the nature-based school model inherently supports sustainability by creating learning spaces that are adaptive, flexible, and have minimal environmental impact [3]. This aligns with global efforts toward achieving the Sustainable Development Goals (SDGs), particularly in ensuring quality education and addressing climate action through environmentally conscious learning environments.

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2.2 Sustainable Architecture

Sustainable architecture is a design philosophy that takes into account the long-term environmental impact of buildings by promoting energy efficiency, the use of eco-friendly materials, thermal comfort, and resource-conscious construction. Core principles include maximizing the use of natural lighting and ventilation, utilizing locally sourced or recycled materials, and implementing efficient systems for managing energy and water consumption [8].

In educational settings, sustainable architecture plays a strategic role in facilitating healthy and productive learning environments. School buildings designed with an emphasis on natural light, cross-ventilation, and climate-responsive features not only reduce operational costs but also improve thermal comfort and psychological well-being for students and educators. Additionally, such architectural approaches offer an immersive learning tool—where the building itself becomes a medium for teaching sustainability [9].

Sustainable architecture can also be synergized with biophilic design, which emphasizes the emotional and biological connections between humans and nature. Through the integration of natural elements such as vegetation, daylight, water, and organic forms, biophilic design has been shown to enhance user experience, reduce stress, and support cognitive performance—particularly in learning environments [10]. The combination of sustainable and biophilic strategies ensures that educational facilities contribute not only to environmental goals but also to human-centered outcomes.

2.3 Nature-Based School Case Studies

2.3.1 Green School Bali

Green School Bali is one of the most globally recognized examples of nature-based education supported by sustainable architecture. Founded in 2007 by John Hardy, the school was designed with a vision to create a learning environment that is fully integrated with nature. Its buildings are constructed almost entirely from bamboo—a rapidly renewable and structurally viable material—demonstrating a commitment to ecological integrity [11]. In addition to its integration with nature, the building features a unique and unconventional form that blends harmoniously with its surroundings, as shown in Figure 1.

The architectural design of Green School Bali embraces openness and passive environmental control. Classrooms are built without permanent walls, allowing natural airflow and light to penetrate the spaces, thus minimizing the need for artificial lighting and mechanical ventilation (figure 2). Innovative cooling systems such as ceiling fans and bubble air-cooling systems are employed to maintain thermal comfort [12]. The spatial arrangement reinforces direct student interaction with nature, making the environment an active part of the educational process.

Moreover, the school curriculum embeds sustainability and environmental education across subjects, ensuring that the built environment and learning content work in tandem to promote ecological consciousness. Green School Bali stands as a holistic model where architectural sustainability and progressive pedagogy coalesce to support the development of environmentally literate future generations [11].

Figure 1. *Green School* Bali's building

Figure 2. Lighting and ventilation in Green School Bali

2.3.2 Nature-Based School Depok

Nature-Based School Depok (figure 3), established in 2006, also applies outdoor experiential learning supported by energy-efficient and environmentally responsive architecture. The school's facilities are designed with semi-open structures that facilitate natural

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ventilation and daylighting, effectively reducing dependency on artificial systems [13].

A hallmark of this school is its extensive use of open spaces, including outdoor classrooms, educational gardens, and natural circulation pathways. Materials such as wood and stone are preferred over concrete or steel to reduce the embodied energy of construction. Instead of conventional walls, wooden railings or permeable barriers are used to maintain a visual and physical connection with the outdoors, fostering a sense of openness and inclusivity in learning [13].

The architectural strategy of Nature-Based School Depok aims to harmonize the built environment with the surrounding ecosystem. This not only minimizes environmental impact but also supports the formation of student character grounded in ecological awareness and sustainable values. The school serves as a localized example of how environmentally sensitive design can be effectively applied within the context of primary education in urban Indonesia.

Figure 3. Nature-Based School Depok

3. RESEARCH METHODOLOGY

This study adopts a qualitative descriptive approach, which is appropriate for exploring spatial, environmental, and contextual aspects of architectural design [14]. The qualitative method allows for an in-depth understanding of site characteristics, environmental potentials, and the integration of sustainable architecture principles within a nature-based educational setting. Through this approach, the study aims to generate a design that reflects both ecological responsiveness and pedagogical functionality.

The research employed two primary data collection techniques: field observation and site documentation. Field Observation was conducted on the selected project site located in Sekupang, Batam. This involved direct assessment of environmental features such as sun path, prevailing winds, vegetation patterns, noise levels, and views. These factors were crucial in determining the spatial orientation, layout, and zoning of the proposed school design. Site Documentation involved the collection of visual data including photographs, videos, and sketches. These materials were used to analyze the physical characteristics of the land, existing natural elements, and accessibility. Documentation also included the mapping of vegetation coverage and topography to assess the potential for integrating green infrastructure into the design.

The research methodology was outcome-oriented, meaning that all analytical and design decisions were directed toward developing a functional and sustainable school prototype. The outcome was not limited to conceptual drawings but extended to spatial planning, material selection, environmental performance, and educational impact. The resulting design was then critically analyzed in the discussion section in terms of spatial effectiveness, energy efficiency, and alignment with the pedagogical objectives of nature-based education.

4. RESULT AND DISCUSSION

4.1 Site Inventory and Environmental Context

Figure 4. Research location

The project site is located on Jl. R. Soeprapto, Sungai Harapan, Sekupang, Batam City, Riau Islands Province, covering an area of approximately 6,400 square meters that can be seen in figure 4. The site is adjacent to SMA Negeri 1 Batam and in proximity to residential and religious facilities, such as Perumahan Shangri-La and Masjid Al Mizan. The surrounding environment includes dense vegetation to the north, which offers scenic and ecological value, making it a suitable orientation for nature-based educational activities. Details

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Analysis of solar exposure shows that maximum daylight occurs between 12:00 and 14:00, suggesting a strong potential for the application of passive solar design strategies. Prevailing winds come from multiple directions, supporting the integration of cross-ventilation systems. The site also contains a variety of natural vegetation, including shrubs, grasses, and mature trees, which can be preserved and incorporated into the design to enhance microclimatic comfort.

Noise mapping categorizes environmental sound into three levels: high (west and east), medium (south), and low (north). High noise sources include nearby roads, the neighboring mosque, and academic activities at the adjacent high school. As a mitigation strategy, vegetation buffers and strategic spatial zoning are proposed to reduce auditory disturbances, particularly in learning areas. Further information on the site analysis is presented in Figure 5.

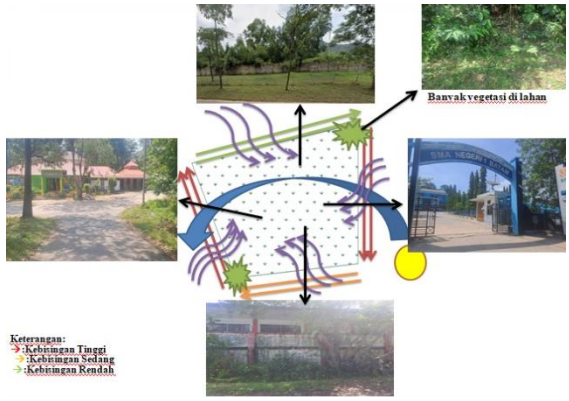

Figure 5. Site analysis

a) Following data collection and analysis, the design process proceeded through the following stages:
b) Site Programming and Spatial Zoning. Functional zoning was based on three categories: public, semi-private, and private areas. This organization ensured optimal circulation, accessibility, and privacy based on user needs.
c) Sustainable Design Integration. Sustainable architectural principles were applied throughout the design, including the use of natural lighting via large windows, implementation of cross ventilation systems, and selection of eco-friendly materials such as bamboo and timber. Vegetation was preserved and enhanced to support thermal comfort and aesthetic integration with the natural landscape.
d) Biophilic and Educational Design Elements. The design incorporated biophilic strategies by introducing open-air classrooms, green courtyards, and outdoor activity zones that connect students with nature. Spaces were also designed to support active learning, with the inclusion of educational gardens and outdoor laboratories.
e) Architectural Form and Inspiration. The final design was inspired by the form of a butterfly, symbolizing harmony and transformation. This concept influenced both the layout and facade of the buildings, creating a sense of balance and visual coherence.

4.2 Spatial Program and Functional Zoning

The spatial program was developed to accommodate both indoor and outdoor educational activities. A total of 17 types of functional spaces were identified, including classrooms (indoor and outdoor), administrative offices, a library, laboratories, health facilities (UKS), sports fields, educational gardens, and communal green spaces.

The zoning strategy divides the site into three main categories:

1) Public Zone: Accessible to all users, including parents and visitors. It includes the parking area, canteen, library, and open green spaces.
2) Semi-Private Zone: Restricted access requiring supervision or permission. This zone comprises outdoor classrooms, sports areas, and medical facilities.
3) Private Zone: Reserved for students, teachers, and staff. It consists of indoor classrooms, administration offices, archives, and secure storage areas.

This arrangement ensures a balance between accessibility, privacy, and functionality, enhancing safety and learning quality while minimizing disruptions.

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4.3 Sustainable Design Strategies

The design incorporates a range of sustainable architectural principles:

1) Natural Lighting: Large operable windows and skylights are integrated throughout the classrooms and shared spaces to maximize natural daylight, reducing reliance on artificial lighting.
2) Cross Ventilation: Strategic window placement on opposing walls enables effective air circulation, enhancing thermal comfort and reducing energy consumption.
3) Eco-Friendly Materials: Bamboo and timber are selected as primary construction materials due to their renewability, thermal properties, and low environmental impact.
4) Vegetation Preservation: Existing trees and green areas are retained and supplemented to provide shade, reduce heat gain, and strengthen the site's ecological identity.

In addition, rainwater harvesting and passive cooling mechanisms are proposed to optimize water and energy usage, supporting long-term sustainability.

4.4 Biophilic and Educational Integration

The project applies biophilic design elements not only to connect students with nature, but also to enhance their mental and emotional well-being. Key strategies include:

a) Open-Air Classrooms: Outdoor learning areas located within gardens and green courtyards support hands-on, experiential learning.
b) Visual and Physical Access to Nature: Almost every building is designed with views toward vegetation and open landscapes, reinforcing a constant sensory connection with nature.
c) Interactive Green Features: Elements such as educational gardens, composting areas, and planting zones function as both teaching tools and sustainability features.

These design decisions align with nature-based pedagogy, where physical interaction with natural systems plays a crucial role in cognitive and emotional development.

4.5 Form and Architectural Expression

Inspired by the symmetrical form of a butterfly, the architectural layout reflects balance, transformation, and connectivity. The central spine of the layout functions as a circulation corridor, connecting key learning spaces, while the "wings" contain classroom clusters and outdoor activity zones (figure 6). Other reason for using the butterfly shape concept is because a design that directly involves natural elements will improve the quality of the space experience for its occupants [15].

Figure 6. Site design concept transformation

This symbolic form enhances spatial orientation, encourages exploration, and subtly communicates ecological values through form and function. The façade design also incorporates natural patterns and textures, contributing to the visual harmony between the built environment and its surroundings.

4.6 Design Development

Figure 7. Site plan

Based on the site plan (figure 7), the layout of the teaching and learning buildings is

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arranged in close proximity to facilitate efficient student movement and minimize transition time between activities. The parking area, canteen, playground, access roads, and green spaces are positioned near the site entrance, allowing external users to access these facilities without interfering with the academic environment. The administrative building is strategically located at the center of the site, near the canteen, playground, and classrooms, to ensure convenient access for staff in conducting educational activities, social interaction, and student supervision. At the rear of the site, a learning garden is provided where students can engage in gardening activities, which not only enhance their environmental knowledge but also support the development of fine motor skills.

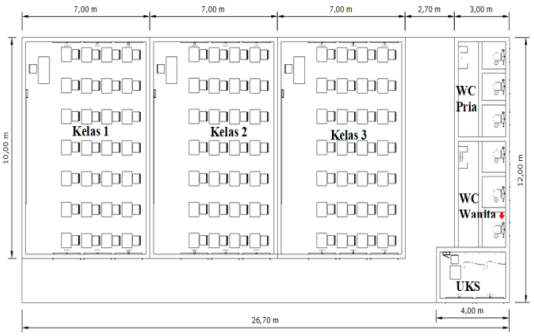


Figure 8. Classrooms floor plan (Grades 1-3)

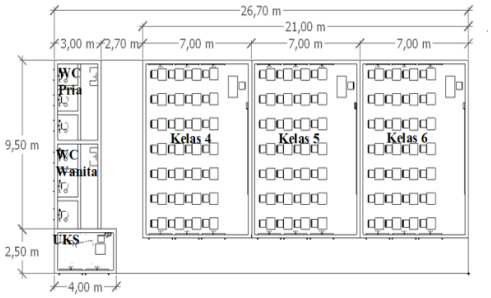


Figure 9. Classrooms floor plan (Grades 4-6)

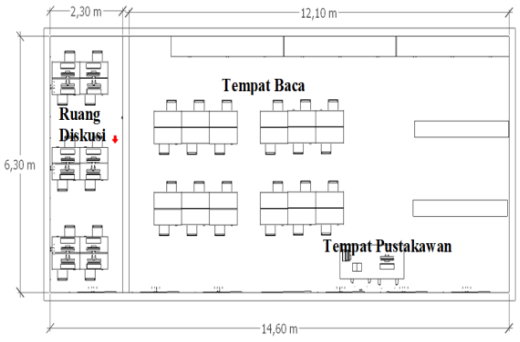
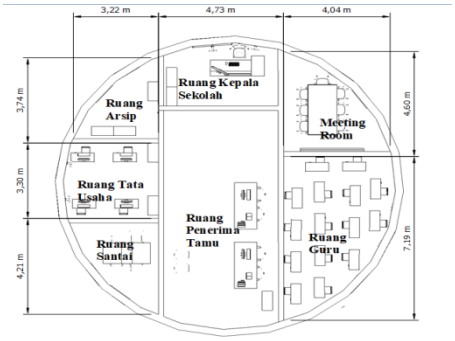


Figure 10. Library floor plan



Gambar 11. Office administrative floor plan

The classroom floor plan (figure 8 and 9) shows that Grades 1 to 3 are consolidated into one building, while Grades 4 to 6 are grouped into a separate structure. In the library floor plan (figure 10), the discussion area is intentionally placed in a separate room from the reading area to minimize disruptions to students engaged in reading activities. The librarian's desk is situated within the reading area to enable supervision and maintain order within the space. In the administrative building (figure 11), the reception area is located near the principal's office and the teachers' room to allow visitors direct access to the principal without interrupting staff activities. Private spaces such as the archive and meeting rooms are positioned deeper within the building to ensure a higher level of privacy. Conversely, rooms frequently accessed by students are located near the entrance to enhance time efficiency and circulation flow

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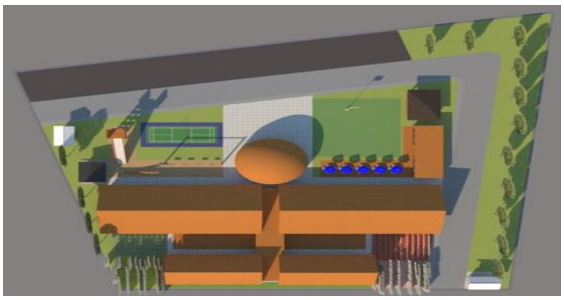

Figure 12. Top elevation

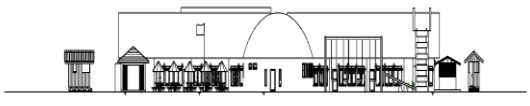

Figure 13. Front elevation

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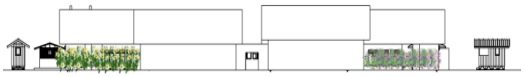

Figure 14. Back elevation

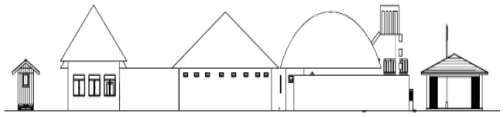

Figure 15. Right side elevation

Figure 16. Left side elevation

The elevation drawing (figure 12 to 16) reveals a school building configuration with zoning that supports student learning activities. Several open spaces are integrated to create harmony between the built environment and nature, serving as both play areas and informal learning spaces for students. Additionally, the presence of vegetation throughout the site enhances the green atmosphere and contributes to a more comfortable and pleasant environment for the students.

Figure 17. Area cross-section

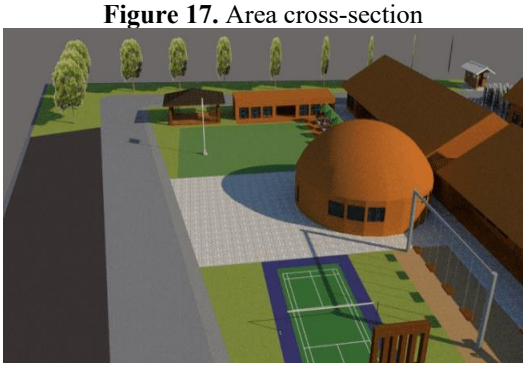

Figure 18. Green area and the school's front building

Figure 19. Classroom exterior

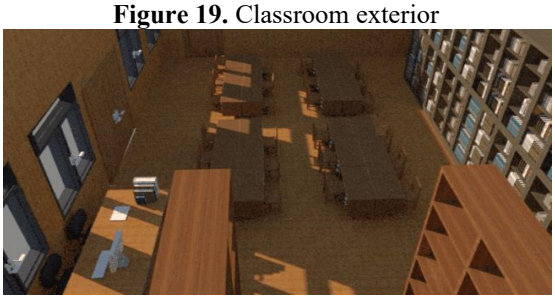

Figure 20. Library Interior

From the exterior and interior design, it can be observed that the implementation of sustainable architecture lies in the use of numerous large windows to maximize natural sunlight, thereby reducing electricity consumption. Additionally, a cross-ventilation system is applied to ensure effective air circulation in each room. It is also evident that each building utilizes environmentally friendly materials, such as bamboo and wood, which contribute to energy efficiency by reducing the need for artificial heating and cooling systems.

5. CONCLUSION

This study reaffirms the importance of applying sustainable architectural principles in the design of nature-based elementary schools to create healthy, energy-efficient, and environmentally responsive learning environments. Guided by the central research questions—how sustainable architecture can support experiential learning and environmental awareness in tropical urban settings—the research demonstrated that the use of natural lighting, cross-ventilation, and eco-friendly materials such as bamboo and timber can significantly reduce energy consumption while enhancing user comfort and well-being.

The integration of biophilic design elements—such as open-air classrooms, green courtyards, and

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visual access to nature—not only strengthens students' emotional connection to the environment but also serves as a pedagogical tool that promotes sustainability values. By situating architecture as both a spatial and educational medium, this study contributes to the growing body of literature on green school design, particularly within the context of Southeast Asia.

Nonetheless, this study has several limitations. The design proposal was based on a single case study in Batam, with limited empirical evaluation of user responses and long-term performance. Financial constraints, technical feasibility, and regulatory factors were also beyond the scope of this research. As such, the actual implementation of the proposed strategies may face practical challenges.

Future studies are recommended to incorporate post-occupancy evaluations to assess the real-world effectiveness of sustainable school designs. Additionally, broader interdisciplinary collaboration—combining architecture, education, environmental psychology, and policy—would enable more comprehensive frameworks for implementing sustainable and nature-based learning environments across diverse geographical and socio-economic contexts.

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