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RENOVATING OUTDOOR SPACE OF PUBLIC SCHOOLS IN HANOI TOWARDS GREEN BUILDING CRITERIA

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Abstract

Developing outdoor spaces of schools towards green building criteria not only provides better learning and recreational conditions for pupils but also educates young generation about environmental conservation and sustainable development. In addition to new construction, renovation of existing outdoor spaces can expedite the realization of these values while optimizing resource use. This paper explores the potential of outdoor landscapes in public schools, ranging from primary to high school levels in Hanoi, with a particular focus on schools in need of renovation. The aim is to harness this potential to meet the increasingly urgent demands for green development. Contributing to this direction, the paper applied inheritance method to synthesis published research findings and applied observational methods to assess the current situation of outdoor spaces at public schools in Hanoi, which served as the basis for identifying research issues. Practical experiences were analyzed and summarized in this paper to propose suitable solutions. Throughout the research process, three main green building criteria were identified: natural cooling and lighting; outdoor air quality and vegetation; sustainable water and stormwater management. Together with this result, analyzing the actual investigation data of Hanoi public schools helps the research team identify the renovation requirements. To meet these requirements and align the three main green building criteria, four solution groups were proposed for typical cases: sunshade enhancements, vegetation improvements and upgrades, drainage systems enhancements and water reuse, and solutions to reduce the urban heat island effect.

Keywords: school outdoor space; Hanoi public school, outdoor space renovation; outdoor space sunshade; urban heat island effect.

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1. Introduction

School can be defined as a complex of inside and outside classroom spaces for cognitive and thinking development, social and emotional abilities of children [1]. So outdoor spaces are as important as indoor space, because they help children develop physically, mentally and integrate with their surroundings. The games and physical activities that children pursue in the playground are part of the school's educational activities. Outdoor spaces can actively educate young generations about environmental conservation. School outdoor space provides conditions in terms of landscape architecture, ecosystem, and microclimate for the surrounding facilities, thereby having great potential in enhancing energy efficiency and ensuring quality of space and air for school. To realize these potentials, outdoor spaces and school buildings should be developed towards green building criteria. That's because "green building" is the practice of creating structures and using processes that are

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environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort. Green building is also known as a sustainable or high performance building [2]. Taking a broader perspective, the development based on green building criteria and environmental education for the young generation represents opportunities for schools to contribute to climate change mitigation, which is recognized as one of the biggest global challenges [3], demanding effective strategies, commitments, and actions to reduce greenhouse gas emissions, which are closely related to energy use processes.

Hanoi is the largest education center in Vietnam. In recent years, the number of schools, classes, and pupils at all levels in the city has been steadily increasing. According to the data released by the Hanoi Department of Education and Training, there are 1.749 public schools in the city, including 1.473 primary schools, 619 secondary schools, and 126 high schools, accounting for 84% of the total [4]. Due to the different construction periods of these public schools, many of them require renovation, upgrading, or new construction. The outdoor space, or in other words, the landscape architecture of these schools, is generally limited by function for concentrated activities such as sports, flag ceremonies, or season events. Public school projects mainly focus on classrooms and infrastructure for indoor activities [5]. Therefore, it is essential to research the role of outdoor space in Hanoi's public schools and develop effective approaches for their renovation.

This paper will focus on researching the outdoor spaces of public schools in Hanoi with the primary goal of renovating them towards green building criteria. The specific objectives include: identifying main green building criteria for the renovation of outdoor spaces in public schools and proposing solutions to effectively implement these green building criteria. The scope of the study encompasses public schools from primary to high school levels in Hanoi, with a particular emphasis on schools that require renovation.

The three research questions posed are as follows: What role do outdoor spaces play in school? Which green building criteria are the most necessary and feasible for renovating outdoor spaces of public schools in Hanoi? How should the outdoor spaces of public schools in Hanoi be renovated and improved towards main criteria of green building?

This paper used the following research methods to achieve the stated objectives:

- Inheritance method: The research team collected and analyzed published studies related to the outdoor spaces of schools to provide scientific basis for this study. Additionally, sustainable development solutions, both domestically and internationally, were synthesized and used as lessons for proposing solutions to renovate the outdoor spaces of public schools in Hanoi.

- Observational method: The research team collected data from 19 schools selected based on two criteria: First, representing each region in the three main areas of Hanoi divided by urban characteristics and historical formation, including the central area (4 inner districts), the new districts (8 remaining districts), and the suburban area (rural region). Second, belonging to the group of schools with renovation plans during the 2021-2025 period according to the plan of the Hanoi Department of Education and Training. Applied observational method includes three investigations as described below. Through these activities, the research team will determine the requirements for renovating outdoor spaces towards green building criteria.

In the first investigation, the research team gathered general plan drawings from the Hanoi Department of Education and Training, collected satellite images from Google Maps, and took on-site photographs at the schools. After cross-referencing and analyzing the collected information, images, and drawings, some indicators were identified. In which, the classroom window orientation is as-

sessed to be unfavorable by solar radiation when it is deviated from the North-South axis more than 22.5 degrees and there is not shading by higher buildings.

In the second investigation, using dust meter (Microdust Pro Cel 712 - UK; INGRESS – China), the research team collected data on the concentration of fine particulate matter (PM2.5) in the air within the classrooms, corridors, and in the school yard. This task was conducted during regular school hours and at two time: the first time in early summer (late April, early May 2022) and the second time in early winter (December 2022). In case of middle classroom, the measurements were taken during class sessions, ensuring an adequate pupil presence.

In the third investigation, using thermal and humidity meter EXTECH 45170 – Taiwan, the team collected air temperature data by monitoring the inside and outside of the classrooms to identify issues related to thermal comfort. The temperature measurements were conducted at two time: the first time in early summer (late April, early May 2022) and the second time in early winter (December 2022). In case of middle classroom, the measurements were taken during class sessions, ensuring an adequate pupil presence. The sampling conditions required the classrooms to be without the use of air conditioners or electric fans. If the classroom had air conditioners or fans, they were turned off 20 minutes before the monitoring measurements.

2. The role of outdoor space in schools

Firstly, the impacts of green spaces on children's learning should be mentioned. Green spaces are elements that embody natural features and can be integrated into the outdoor areas of schools. One of the most prevalent perspectives on educational spaces is that exposure to nature is beneficial for children's development [6]. Many studies have investigated the effects of physical environments on children's development, particularly the positive effects of outdoor environments. Research results have indicated significant positive effects of outdoor environments on learning, learning through play, and physical activity [7]. Japanese children are taught about many aspects of nature, from the overall cycles of nature to details such as the changing colors of trees. It is believed that nature must be part of children's daily experiences in order for them to recognize its beauty, mystery, and appreciate its changes over time [8]. A study of 219 public schools in Columbia indicated that trees are an essential part of healthy living. Specifically, schools with more trees had a higher percentage of proficiency or advanced performance in Mathematics and Reading [9] Along with the general educational and skill development goals for pupils, green and biodiverse outdoor spaces also promote environmental education. The aim of environmental education is to make human beings gain an understanding of the ecological balance and their own roles in this balance; to enable them to develop ideas about how to live together in harmony with the planet; and to make them gain the necessary skills needed for effective and liable participation [10]. Therefore, green spaces with abundant natural experiences have a positive impact on children, helping them learn better and develop in a healthy manner.

Secondly, when considering the role of playgrounds, an increasingly emphasized component in schools, several noteworthy points can be observed. Children integrate into society and learn about the environment around them through experiences in physical spaces, particularly playgrounds [11]. Children engage in outdoor activities based on the abilities provided by the environment and their own desires, and through these activities, children's learning occurs naturally [12]. This means that if outdoor spaces in schools are designed to be diverse, providing many opportunities for play, exploration, or learning, children will learn more and develop more comprehensively. The important role and great value of playgrounds in schools have also been affirmed by Jones, E. [13]. Reality and practice are more effective ways of learning for children than theoretical learning. At the same time, children at school age explore themselves and their surroundings comfortably through play [14] Many scientific

disciplines are contributing to the development of playground and school yard design solutions that enhance children's learning. These solutions have a dual purpose of nurturing children's psychological and cognitive development, while also encouraging environmentally responsible behavior [14] Therefore, a well-designed outdoor space with playgrounds and school yards can bring numerous benefits to pupils, as well as to teaching and learning in particular, and to the community as a whole.

Additionally, the interaction between outdoor and indoor spaces in terms of classroom microclimate also needs to be considered. When provided with appropriate ventilation pupils perform academically better. There is compelling evidence that productivity and the health of occupants in general, and pupils in particular, are closely related to ventilation [12]. Furthermore, in the tropical monsoon climate conditions of Hanoi, natural ventilation plays a crucial role. However, the effectiveness of natural ventilation in classrooms relies on the quality of outdoor airflow. Put simply, natural ventilation in classrooms is only effective when the air in the outdoor spaces of the school is clean and properly circulating. Similarly, adequate natural lighting has a significant impact on reading comprehension, vocabulary, and science outcomes [15]. The availability of natural lighting in classrooms depends on both buildings' architecture and general plan design, which includes outdoor space solutions. Therefore, when renovating outdoor spaces in schools, it is essential to consider how to support and create optimal conditions for natural lighting in classrooms.

Outdoor spaces play an important role in school due to significant potential to support pupils' education and development, as well as notable ability to enhance the indoor environment quality of classrooms. To fully leverage this role, it is necessary to increase diverse and natural outdoor spaces, provide ample play areas, and implement solutions that improve air quality, ventilation, and appropriate sun shading measures.

3. The main green building criteria for renovating outdoor spaces of public schools in Hanoi

Green building certifications are developed and promoted by professional associations or research organizations, targeting the design, construction and operation of buildings to meet green building requirements. The most populated assessment systems include Building Research Establishment Environmental Assessment Method (BREEAM – the UK), Leadership Energy Environment Design (LEED – the USA) and sustainability rating system for buildings in Australia (GREENSTAR). The Vietnamese green building certification system, known as LOTUS, released its first version in 2010, and now it has the third version, which is being increasingly adopted. The research results indicate that "Sustainable sites" ranks second in weight among LEED criteria, while "Land use and Ecology" ranks fifth in weight among BREEAM criteria [16]. Meanwhile, "Site and Environment" accounts for 21% of the total weight and ranks second among the LOTUS criteria [17]. Therefore, the most commonly used green building assessment criteria systems in Vietnam all emphasize the significant and indispensable role of outdoor spaces in meeting green building criteria. This reaffirms the urgency mentioned in the introduction of the research on renovating outdoor spaces in Hanoi's public schools towards green building criteria. To align these solutions to specific conditions, the research team has identified three main criteria based on popular assessment systems and local school conditions.

LEED, BREEAM and GREENSTAR pay attention to energy, or more specifically, the efficient use of energy, which is the most significant aspect when evaluating the environmental sustainability of buildings in non-detachable relationship with surrounding space [16]. At the same time, LOTUS allocates 32% of its evaluation weight to the energy aspect [17]. According to the investigation results conducted by the research team, the open and decentralized layout of classrooms in public schools in Hanoi heavily relies on natural ventilation and lighting conditions to provide indoor comfort; the majority of electrical energy in Hanoi's schools is consumed to maintain ventilation, cooling, and light-

ing purposes; heating can be efficiently achieved by ensuring the insulation of the building envelope and the airtightness of door systems, often without the need for complex mechanical equipment and with minimal energy consumption. Hence, when refurbishing outdoor spaces in schools, the emphasis should be placed on solutions that improve *natural cooling and lighting*. It will require appropriate shading solutions and the reduction of urban heat island effects.

LEED ranks 'Indoor Environmental Quality' as the third most important category, while BREEAM assesses 'Indoor Environmental Quality' and GREENSTAR assesses 'Health and Well-being' as the second most important category in their assessments [16]. Indoor environmental quality or health and well-being criteria are based on achieving thermal comfort and air quality in classrooms. Thermal comfort in classrooms was mentioned above. Air quality, on the other hand, depends on various environmental factors both inside and outside the classrooms, including the concentration of harmful components in general and PM2.5 in particular, as this fine particulate matter has adverse effects on health [18]. Meanwhile, one of the most effective solutions to improve outdoor air quality is to enhance vegetation [18]. Therefore, improving *outdoor air quality and vegetation* is the second green buildings criterion when renovating outdoor spaces in schools.

Regarding water aspects in general and outdoor water in particular, LOTUS, serving as a green building assessment system for Vietnam, offers criteria suitable for application in schools, including those related to stormwater management and sustainable water solutions. The last one emphasizes recycled, reused, harvested water and can carries 2.5 times more weight than the first one in the assessment system [17]. This is meaningful for outdoor space renovation towards green building criteria because, in addition to the water needed for sanitary facilities, landscape maintenance and operation, water in these schools is also required for surface cleaning, cooling and mitigating the urban heat island effect. Furthermore, water reuse contribute to reducing pressure on the overloaded drainage systems in certain areas of the city. Therefore, the third criterion for outdoor space renovation towards green building criteria should be defined as solutions that improve *sustainable water and stormwater management*.

4. Current situation of open spaces at public schools in Hanoi and their renovation requirements towards green building criteria

Hanoi's public schools are typically located in residential areas or in close proximity to heavily trafficked roads. For example, Dinh Cong Primary School is 200 m away from Ring Road 2.5, while Quang Trung - Dong Da High School is just 42 m away from Ring Road 2. The presence of dust generated by traffic activities can significantly impact the air and environmental quality within the school premises. To provide a clear understanding of the outdoor spaces in Hanoi's public schools and to identify issues related to the aforementioned three main criteria, the research team conducted three investigations at 19 schools. The schools selection criteria and the investigation conducting ways were outlined in the Methodology section.

Based on the findings of the first investigation, the analysis of outdoor spaces in Hanoi's public schools, as shown on Table 1, reveals the following:

- About 53% of classrooms have an unfavorable window orientation in terms of solar radiation affect. In addition, 9 out of 19 schools have outdoor areas that lack sun shading, ranging from 25% to 78% of total outdoor area. This highlights the necessity of mitigating the adverse effects of sunlight on indoor spaces, corridors, and outdoor areas during hot periods, which can be achieved by adding appropriate shading solutions – Requirement number 1.

- Three schools in the central and new districts area (accounting for 16%) do not have sufficient outdoor space according to the National Design requirements. The draft National Design requirements

for primary schools [19], secondary schools and high schools [20] stipulate a minimum playground area of 1.5 m^2 per pupil. In cases where there is a shortage of playground area, integrated measures should be considered and applied. Among these measures, the implementation of transformable semi-outdoor spaces can effectively utilize the limited available outdoor space while also adapting to weather conditions [21] – Requirement number 2.

- Except for Xa Dan School, specialized institution for deaf children, all other schools have a main yard, enough to accommodate a basketball court. In the main yard area, a multifunctional space should be created, where besides serving ceremonial and cultural activities, there should be arrangements for standard-sized or small-sized basketball courts (3×3 format) and badminton courts – Requirement number 3. This is a requirement aimed at enhancing the usability of outdoor spaces, thereby maximizing cost-effective investments while realizing the important roles mentioned for outdoor spaces.

Table 1. General plan analytic data of 19 public schools in Hanoi

Investigated schools (PS.: Primary School SS.: Secondary School HS.: High School)	Unfavorable window orientation	Main yard area	Total area of outdoor space	Outdoor area per pupil, m^2	Indoor sports court	Outdoor sports court	Lack of sun shading, %
PS. Dinh Cong (New district)	100%	892.8	2681.8	1.49	Badminton	NA	22
PS. Den Lu (New district)	0%	1157	4013.3	2.79	Basketball 3×3	NA	33
SS. Tan Mai (New district)	24%	1169	2849.5	0.96	Basketball	NA	78
HS. Xuan Khanh (Suburban)	0%	1373.5	6767.8	5.57	Badminton	NA	22
PS. Ngo Tat To (Suburban)	100%	1773.8	5067.8	3.75	Badminton	NA	29
SS. Nguyen Khe (Suburban)	100%	1887.4	10403.3	7.01	Basketball 3×3	NA	35
HS. Dong Quan (Suburban)	100%	4004	9358.8	5.78	NA	NA	22
HS. Dai Cuong (Suburban)	25%	2057.3	5570.3	3.87	Badminton	NA	41
HS. Nguyen Trai (Suburban)	58%	1923.5	8917.3	4.61	Basketball	Basketball	33
HS. Tien Phong (Suburban)	100%	1432.4	4260.5	3.55	NA	Basketball	20
HS. My Duc (Suburban)	100%	4664	9968.5	7.44	NA	NA	27
HS. Viet Duc (Center)	40%	1184	7443.2	3.38	Basketball 3×3	NA	19
HS. Tran Phu (Center)	0%	1844.8	3080.5	3.26	Badminton	NA	21
SS. Xa Dan (Center)	40%	215.8	467	2.34	NA	NA	52
SS. Nguyen Dinh Chieu (Center)	25%	754	8290	4.88	Basketball	Football	23
PS. Thinh Quang (Center)	59%	786.1	1764.4	1.45	NA	NA	27
HS. Le Quy Don (Center)	0%	901.8	6349.8	3.36	Badminton	Basketball	18
HS. Dong Da (Center)	100%	1479	5081.5	4.18	Basketball	Basketball	12
HS. Quang Trung (Center)	40%	2035	7946	3.97	Basketball	Basketball	12

The findings of the second investigation show that, the indoor and outdoor data on PM2.5 concentration are relatively correlated, meaning they both increase or decrease at specific times with an average difference of about 0.00426 $\mu m/m^3$ (Fig. 1). In some cases in central Hanoi this index exceeds the safe level 0.025 μ/m^3 recommended by WHO [22], and in most other cases, the PM2.5 index is close to the aforementioned WHO threshold. Although the PM2.5 index exceeded the recommended level at specific time (April 19th and 21st, 2022) and in certain locations, the fluctuation of this index near the recommended threshold highlights the need for solutions to improve air quality within the school premises - Requirement number 4. It is important to note that in 2018, Hanoi was assessed as the second most air-polluted city in Southeast Asia [23].

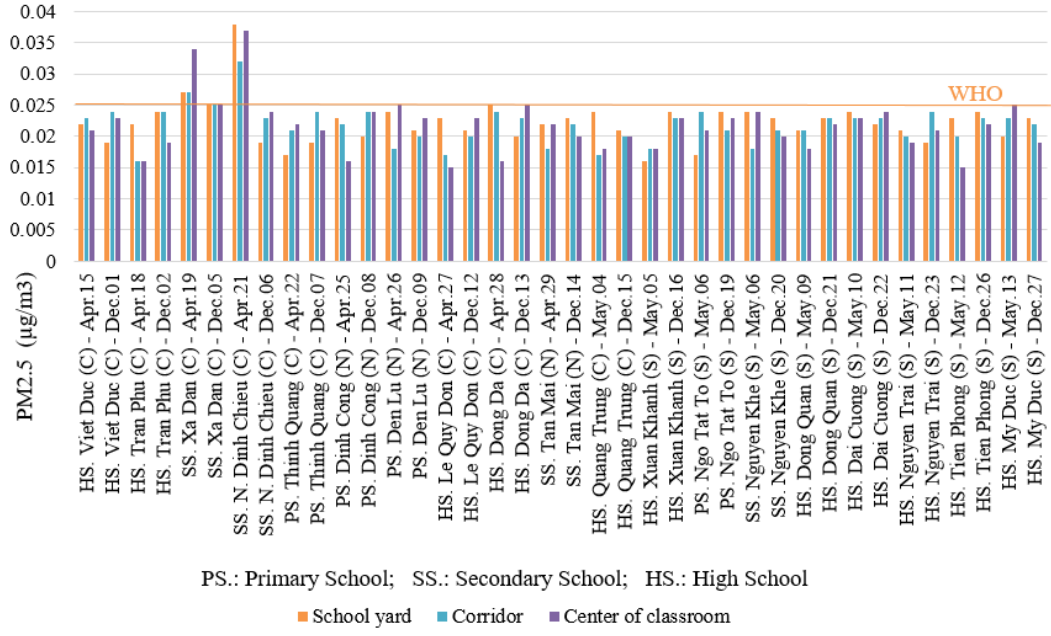

Figure 1. PM2.5 index measured at some public schools in Hanoi

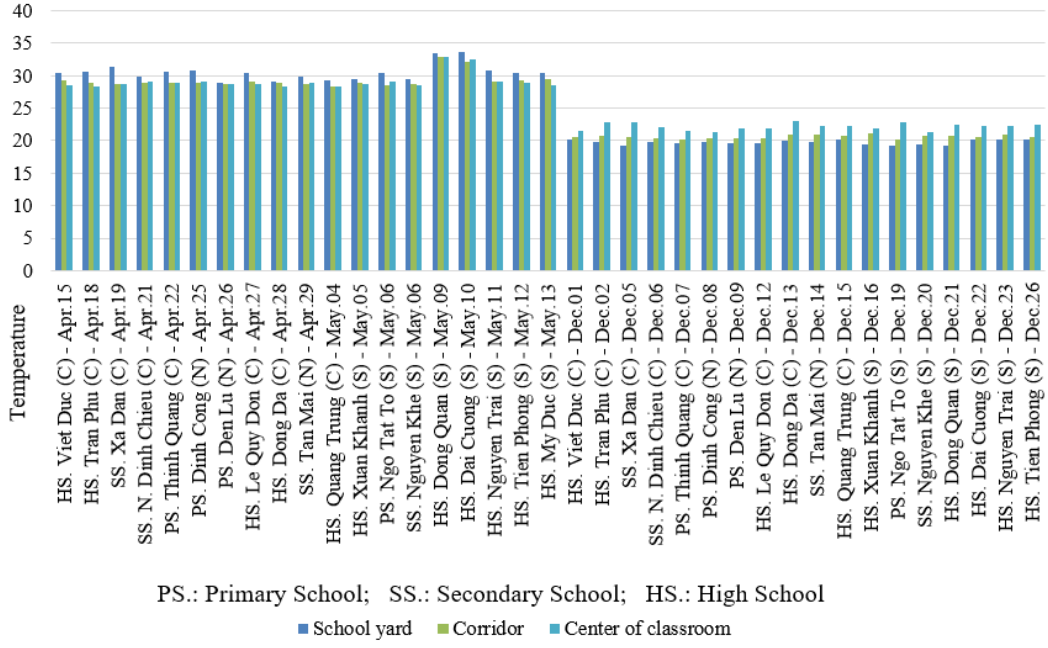

Figure 2. Inside and outside temperatures of some public schools in Hanoi

The presented in Fig. 2 measurement results of the third investigation demonstrate a small temperature difference between the classroom without air conditioner and the school yard during the summer season (ranging from 0.3 to 2.5 degrees). The highest air temperature is observed in the school yard, gradually decreasing from the open space to the corridors and inside the classrooms. The temperature difference between the classroom and the school yard is slightly larger during winter (ranging from 1.3 to 3.6 degrees). In this case, the lowest air temperature is found in the school yard, gradually in-

creasing from the open space to the corridors and classrooms. Therefore, the indoor air temperature in the classrooms closely depends on the external environmental temperature. Consequently, if the negative impacts of solar radiation and the urban heat island effect during summer can be mitigated in the outdoor spaces of the school, significant reductions in the use of electricity for cooling the classrooms can be achieved. This requires reducing the heat absorption of school yard surfaces in Hanoi – requirement number 5. This entails implementing additional measures, including the provision of shading and vegetation cover for outdoor spaces, while ensuring compliance with safety, sanitation standards, and functional requirements.

5. Solutions

To find renovation solutions for the existing issues of outdoor spaces in public schools of Hanoi, as well as to meet the five requirements mentioned above, the research team has synthesized research findings and incorporated practical experiences to propose the following solutions.

5.1. Sunshade enhancing solutions

Requirements 1, 2, and 5 mentioned above emphasize the importance of enhancing sunlight shading in the outdoor spaces of schools to make them suitable for multifunctional use such as playgrounds for sports activities. These shading solutions should be integrated, addressing functional, landscape, technical, and operational requirements simultaneously. These enhanced shading solutions are highly recommended for schools with a large number of classrooms with unfavorable windows orients as listed in Table 1.

The first solution involves increasing the green area for shade with adequate tree care and pruning (Solution 1a). The selection of trees is guided by the Vietnam construction standard TCVN 9257:2012, which provides design requirements for greenery planning in urban public utilities. The main challenges in managing and developing greenery in schools stem from a lack of professional staff, limited land availability, and the difficulty of balancing teaching activities with tree care for pupils [24]. To overcome these difficulties, in addition to the efforts and resources of the school, stakeholder engagement is crucial. This includes actively involving pupils, parents' associations, and widely sharing information to mobilize community resources. This approach ensures the principle of engaging relevant parties when implementing school renovations according to green construction criteria [1, 25]. The research has also demonstrated that the opinions of these various stakeholders complement each other rather than contradict each other entirely [26].

The second solution involves incorporating retractable roof systems to create multifunctional open spaces, with one of the desired functions being a playground (Solution 1b). This solution is particularly effective for schools with insufficient space for playgrounds comparing with design requirements. Equipping these playgrounds with retractable roofs is an effective means of adapting to Hanoi's climate conditions [21]. By utilizing a steel truss suspension system, these roofs can span from 18 to 50 meters, allowing them to cover a sports field. With advancements in structural steel and mechanical solutions, the application of retractable roofs for large outdoor spaces has become feasible and highly efficient (Fig. 3).

Small and medium-sized outdoor sunshades can serve as fixed roofs for auxiliary areas in schools, such as parking areas, outdoor hand washing areas, and areas for parents to pick up children. Large-sized outdoor roofs for functional areas, such as sports fields, ceremonial fields, outdoor performance or exhibition areas, or other multifunctional areas, should be equipped with retractable roofing systems. It should be noted that these large sunshades require mechanical systems to retract on cloudy days or during the cold winter and humid spring seasons. In January and February, the average daily sunlight hours in Hanoi are less than 2.3 hours [27].

Figure 3. Retractable roof for outdoor space at Cau Giay, Hanoi [28]

The third solution involves adding bridge corridors to enhance connectivity between functional areas and integrating sunshade structures simultaneously (Solution 1c). In densely populated areas of Hanoi, the limited land availability for schools and increasing pupils enrollment have led to increasing in the building coverage ratio of public schools. When school blocks are arranged parallel or interconnected in a U; H-shape, implementing bridge corridors to connect the opposite blocks can achieve the aforementioned benefits (Fig. 4).

Figure 4. Bridge corridor, connecting functional areas and providing additional shade for outdoor space [29]

5.2. Solutions for improving and upgrading vegetation

Besides the shading trees mentioned in Solution 1a, greening outdoor spaces by small, climbing, soft-stemmed plants and flower also plays an important role in improving the outdoor environment, in order to fulfill the requirements outlined in points 4 and 5 mentioned above. Greening can be diverse, from simple solutions of potted plants to more complex solutions such as tree wall or green balcony with automatic watering system. The vegetation addition in schools should be done with adequate landscape design in order to benefit the optimal performance in terms of aesthetics, environment, economic and technical aspects (Solution 2a). Similar to solution 1a, the stakeholders should to be involved in creating, maintaining and developing green spaces in schools. This solution should be implemented in sync with rainwater collection and use as well as automatic watering system. Greening outdoor spaces of schools can be done in the school yard, along the corridors or in schools' bordering areas, fences, entrance gates, etc.

While creating a green roof can be a complex and costly process that involves technical considerations, it is an effective way to transform the appearance of a building, enhance its insulation, and

even create a garden or recreational space on its rooftop (Solution 2b). Despite its complexity, this solution offers significant benefits and has the potential to greatly improve the quality of human being in building. Moreover, it can contribute to the development of sustainable urban environments and help address issues related to climate change. Therefore, it is worth exploring the potential of green roofs and finding ways to make this solution more accessible and affordable.

Besides the solution of growing trees and flowers using land, on yard surfaces, in open spaces or on the roof of buildings, there are new technologies to grow plants without soil such as hydroponics and aeroponics. These solutions are especially effective when adding trees and flowers to the upper floors thanks to their very low load on the building. In addition, hydroponic or aeroponic plants are taken care of automatically and are very clean cause of absence soil as well as associated organisms and microorganisms [30, 31] (Solution 2c). It is important to note that this solution comes with the requirement to build a technical system of water and electricity supply for irrigation.

Maintenance and development of green spaces in schools cannot be without appropriate solutions in their management and operation. The proposed solution to this is that the school needs to do the following general and specific work:

- Make a map to manage the green areas of the school. Each area needs specific managers and caregivers;

- Develop and publish a list of spaces that allow the addition of trees (on ground, on corridors or available parts of the building) and involve class groups and their families to participate in establish green spaces with a commitment to maintain them for a certain period of time;

- Invest in, manage and operate appropriate watering systems. It can be simple pipeline systems that combine manual watering or it can be automatic watering systems;

- Available program on prioritizing and guiding the use of organic fertilizers and/or minimizing the use of chemical fertilizers and pesticides.

5.3. Enhancing drainage systems and water reuse

a. Additional solution for ground drainage

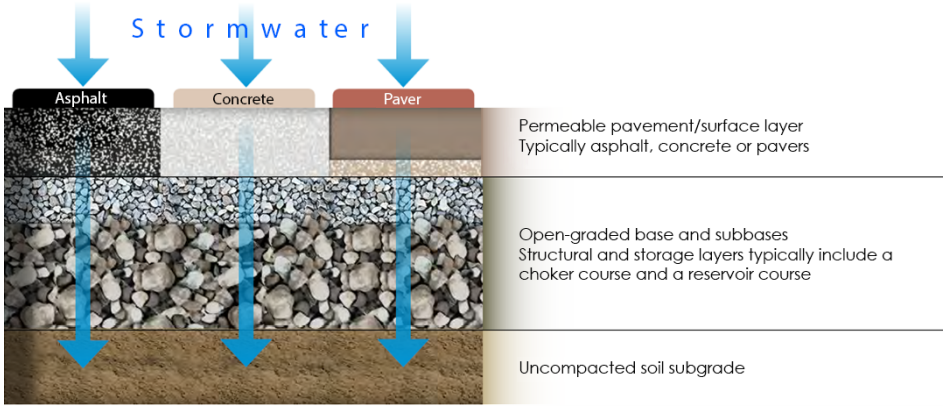

Figure 5. Generic permeable pavement cross-section [32]

Additional solutions for ground drainage and flood resistance in schools are crucial due to the weak drainage systems and the frequently flooding after heavy rains issue of Hanoi. In addition to diverting rainwater into the city's common drainage system, on-site rainwater drainage solutions through permeability into the ground offer several advantages:

- Contribute to decrease the load on the city's common drainage system;

- Facilitating rapid drying of school yards after rainfall, thereby enhancing their usability;
- Preventing the accumulation of stagnant water, mold, and slippery surfaces on hard surfaces.

Applying permeable concrete technology to paved areas (Fig. 5) offers a solution that enables the creation of flat surfaces with adequate load-bearing capacity while allowing rainwater to infiltrate into the ground. This approach effectively reduces surface runoff and contributes to improving the ecosystem [32] (Solution 3a). By implementing this solution, the risk of flooding in nearby urban areas can be mitigated, alleviating the strain on the existing sewerage system. As a result, substantial benefits can be realized in terms of the economy, society, and environment.

b. Water reuse solution

Vegetation maintenance and development, as well as the solutions to mitigate the urban heat island effect (detailed in section 6.4), demand significant and consistent amounts of water. Therefore, water treatment and reuse solutions are essential. In order to minimize wastewater discharge into the environment and ensure wastewater quality, it is crucial to strengthen wastewater management and treatment. The following points should be considered:

- Only use clean water for necessary purposes (drink, cooking and hand washing) and consider using alternative water sources for all other purposes such as toilets, watering plants, outdoor space maintenance and cleaning;
- Implementing a segregated drainage system for rainwater and wastewater is essential to prevent diluting wastewater that might otherwise flow into a centralized treatment facility or an on-site treatment system. Separating these water streams allows for the individual treatment of pollutants, enhancing the purification and potential reuse based on specific requirements.

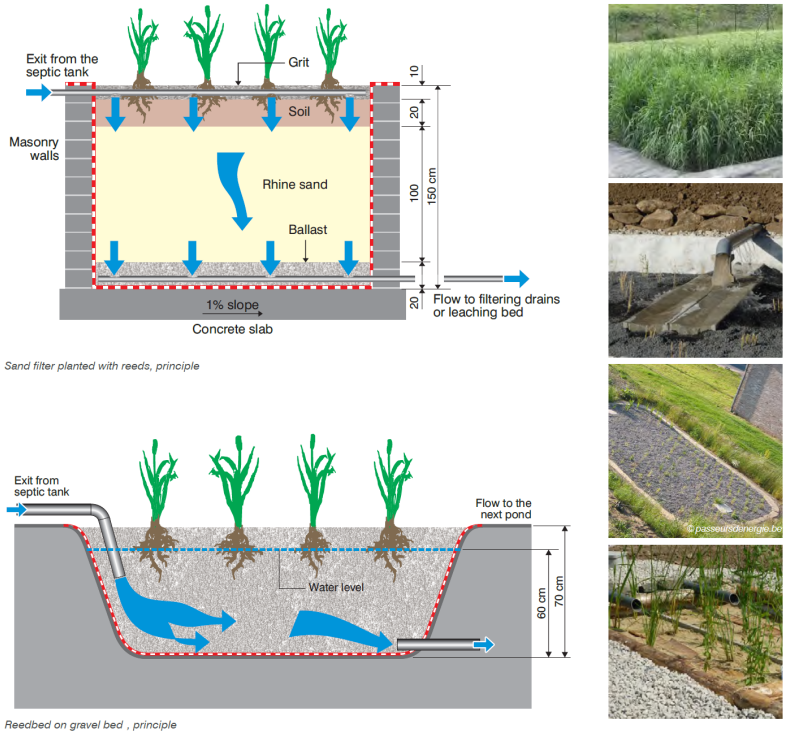

Figure 6. Water reuse solution with extensive water treatment technology [1]

In situations where comprehensive wastewater treatment entails significant investment and operational costs, schools with extensive outdoor areas can adopt the “natural purification” solution, also

known as extended water treatment technology (Fig. 6) (Solution 3b). In this approach, wastewater undergoes preliminary treatment to attain a certain quality before being allowed to permeate through soil areas containing appropriate vegetation. The crucial elements of this solution include: a) the design of an enhanced septic system to achieve the necessary pretreatment quality, and b) the selection of suitable plant species and the design of the planting area to facilitate the biological process that effectively completes the treatment [1].

Besides the above wastewater treatment and reuse solution, with relatively large territory, Hanoi's public schools have a very good opportunity to collect rainwater for purpose of maintaining outdoor space, especially automatic plant watering system and cleaning school yards, playgrounds, paved surfaces and internal walkways. This solution is a prerequisite for Solution 2a and includes:

- Install a rainwater collection system from the roofs of buildings;
- Installation of basic filter and biological sedimentation tanks;
- Build water tanks after basic filtration;
- Build pump and control system to use collected rainwater.

5.4. Solutions to reduce urban heat island effect

The groups of solutions presented in sections 6.1, 6.2 and 6.3 above are all involved in reducing the urban heat island effect. However, to achieve the most comprehensive result, it is necessary to apply the following additional solutions when renovating schools outdoor spaces.

Table 2. Additional solutions to reduce urban heat island effect

Solution	Goal	Applicable cases	Technical, artistic and operational requirements
Using grass pavers (Solution 4a)	Reduce heating of artificial horizontal outdoor surfaces	Improvement of school grounds, parking areas and internal roads	Need to strengthen the underlying layers according to each area's use. For example, ground reinforcement for large size or high load-bearing areas.
Solar panel system (Solution 4b)	2 goals: Sun shade for surfaces and local green energy generation	Improve energy efficiency and shading at the same time	Ensure safety for people, related technical systems as well as for battery panels (installation location, electrical system, wiring and UPS)

For the solution of install solar cells, economic efficiency, along with the payback time of the investment, plays a particularly important role. According to the research results of Nguyen Duc Tuyen, in the condition of Ho Chi Minh City, it takes 98 months (or about 8.2 years) for a solar panel system to reach the breakeven point compared to the plan of sending bank the invested money and use that money along with its interest to pay electricity bills [33]. In the condition of Hanoi, with lower average total solar radiation on the horizontal plane (4541 W/m^2/day for Hanoi compared to 5591 W/m^2/day for Ho Chi Minh City) the time to reach breakeven point is significantly further away. Therefore, the investment in solar panel systems in the renovation outdoor space of public schools in Hanoi needs to be considered with a long-term vision and accompanied by synchronous solutions for effective design, construction and operation.

The matrix in Table 2 demonstrates the potential of each proposal solution to renovate outdoor space of public school in Hanoi towards the three main green building criteria identified in Section 4 and fulfill the aforementioned requirements.

Table 3. Align the proposed solutions with the green building criteria and the identified requirements

Acronym	Requirements	Focused green building criteria		
		Natural cooling and lighting	Outdoor air quality and vegetation	Sustainable water and stormwater management
R	Reducing the negative impact of direct sunlight	1a; 1b; 1c; 4b		
U	Utilize semi-outdoor spaces	1b; 1c		
C	Create a multifunctional playground	1b		3a
I	Improve air quality	1a	2a; 2b; 2c	4a; 3b
A	Additional shading and greenery	1a; 4a	2a; 2b; 2c	3b

1a; 1b; 1c; . . . are separate solution in groups of proposed solutions.

5.5. Apply to typical cases

The selection and application of solutions for each specific case are guided by the analyses and assessments of the proposed solutions detailed below (Table 4).

Table 4. Applying conditions, advantages and disadvantages of proposed solutions

S	Applying conditions	Advantages	Disadvantages
1a	RUWO > 25% or > 25% outdoor area lack of sun shading	Enhancing sunshade and green coverage	Requires growing time, care and pruning; avoid sports practice areas
1b	OAPP < 1.5 m^2 or OAPP < 3 m^2 while RUWO > 50%	Flexibility, sunshade enhancement, and bellow space multifunctionality	Significant investment and contain certain impact on the architecture
1c	U/H-shaped building blocks layout on general plan	Enhancing sunshade and rain shelter; increasing connectivity	Significant investment and contain certain impact on the architecture
2a	An automatic watering system is required	Increasing green coverage	Requires regular care
2b	OAPP< < 1.5 m^2 or total area of outdoor space < 1000 m^2	Increase greenery, thermal insulation, expand outdoor space	Significant investment, substantial roof load increase
2c	Hanoi central area location or OAPP < 1.5 m^2	Lightweight and flexibility in greening	Requires regular care
3a	1.5 m^2 < OAPP < 4.5 m^2	Enhancing surface water drainage	Not applicable to playground surfaces
3b	OAPP > 4.5 m^2 & total area of outdoor space > 4000 m^2	Improving landscape and facilitating water reuse	Requirements of large space and accurate maintenance

S	Applying conditions	Advantages	Disadvantages
4a	High school or 1.5 m^2 OAPP < 3 m^2	Increasing greenery coverage and rainwater drainage	Not applicable to playground surfaces
4b	Increased activity during summer with high energy demand	Enhancing energy source autonomy and increasing sunshade efficiency	High investment costs and the necessity for professional operational management

OAPP: Outdoor area allocation per pupil; RUWO: Ratio of classrooms with unfavorable window orientation.

Table 5. Summary of pilot application for investigated cases

Investigated schools PS.: Primary School SS.: Secondary School HS.: High School	Outdoor area per pupil, m^2	Applicable solutions to typical cases Acronyms of renovation requirements (Table 3)																			
		R				U		C		I							A				
PS. Dinh Cong (New district)	1.49		1b	1c	4b	1b	1c	1b	3a		2b	2c						2b	2c		
PS. Den Lu (New district)	2.79			1c	4b		1c		3a	2a			4a			4a	2a				
SS. Tan Mai (New district)	0.96		1b	1c	4b	1b	1c	1b	3a		2b	2c						2b	2c		
HS. Xuan Khanh (Suburban)	5.57									2a			4a	3b		4a	2a			3b	
PS. Ngo Tat To (Suburban)	3.75	1a								1a	2a				1a		2a				
SS. Nguyen Khe (Suburban)	7,01	1a		1c			1c			1a	2a			3b	1a		2a			3b	
HS. Dong Quan (Suburban)	5.78	1a		1c			1c			1a	2a		4a	3b	1a	4a	2a			3b	
HS. Dai Cuong (Suburban)	3.87	1a		1c			1c			1a	2a		4a		1a	4a	2a				
HS. Nguyen Trai (Suburban)	4.61	1a		1c			1c			1a	2a		4a	3b	1a	4a	2a			3b	
HS. Tien Phong (Suburban)	3.55	1a		1c			1c			1a	2a		4a		1a	4a	2a				
HS. My Duc (Suburban)	7.44	1a		1c			1c			1a	2a		4a	3b	1a	4a	2a			3b	
HS. Viet Duc (Center)	3.38	1a		1c	4b		1c		3a	1a		2c	4a		1a	4a			2c		
HS. Tran Phu (Center)	3.26			1c	4b		1c		3a			2c	4a			4a			2c		
SS. Xa Dan (Center)	2.34	1a			4b				3a	1a	2b	2c	4a		1a	4a		2b	2c		
SS. Nguyen Dinh Chieu (Center)	4.88	1a		1c	4b					1a	2a			3b	1a		2a			3b	
PS. Thinh Quang (Center)	1.45		1b		4b	1b		1b	3a		2b	2c						2b	2c		
HS. Le Quy Don (Center)	3.36			1c	4b		1c		3a			2c	4a			4a			2c		
HS. Dong Da (Center)	4.18			1c	4b		1c		3a	1a		2c	4a	3b	1a	4a			2c	3b	
HS. Quang Trung (Center)	3.97			1c	4b		1c		3a	1a		2c	4a		1a	4a			2c		

1x High-priority solution as it simultaneously meets 3 of the requirements;
2x Priority solutions as each of them simultaneously meets 2 of the requirements;
3x Considered solution (s) (each of them meets 1 of the requirements).

The basis for assessments in the table above includes: Analysis results of data collected from typical schools; school playground area design requirements [10, 20]; technical requirements of the proposed solutions; the feasibility of coordination and overlap among the solutions; economic and technical conditions of schools in different areas of Hanoi. Similar to the specific characteristics of public schools in Hanoi, for instance, high schools require a significant number of parking spaces for bicycles and motorcycles, where can be paved with grass pavers; schools located in the central areas of Hanoi often organize additional educational activities at summer.

Based on the results of on-site and off-site investigations and guided by the instructions in Table 4, the proposed solutions can be applied to typical cases as outlined below. Among these solutions, those that best meet the requirements of renovating outdoor spaces towards green building criteria are given the highest priority.

6. Conclusions

The outdoor spaces in schools play a crucial role and hold significant value for both pupil activities and meeting the green building criteria. They need to be designed, constructed, and operated to provide the best conditions for learning, serve educational purposes in knowledge acquisition, skill development, environmental awareness education, and contribute to sustainable school development. This study collected data, documents, conducted analysis, and identified three main green building criteria that need to be met when renovating the outdoor spaces of public schools in Hanoi. These criteria are: thermal comfort and natural lighting; outdoor air quality; and additional drainage systems and water reuse.

Through the investigation and analysis of outdoor spaces in public schools in Hanoi, the issues of current situation and the requirements for renovation have been identified. These requirements include: additional solutions to reduce the negative impact of direct sunlight; utilization of semi-outdoor spaces; creation of multifunctional playgrounds; improvement of air quality; and additional shading and greenery. In order to renovate outdoor space towards the previously identified green building criteria, four groups of solutions have been proposed, including: sunshade enhancing solutions; solutions for improving and upgrading vegetation; enhancing drainage systems and water reuse; and solutions to reduce the urban heat island effect.

To further deepen and develop the results of this research, it may be necessary to conduct additional studies for each group of schools in Hanoi with their common characteristics in terms of space, urban context, and usage requirements. Specific aspects such as experiential space, multifunctional space, and creative space can also be further studied to identify new solutions.

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