ARPHA Proceedings

Proceedings CAUSummit 2025, 0017-0026
doi: 10.3897/ap.9.e0017

10th Anniversary
World Summit: Civil Engineering-Architecture-Urban Planning Congress

Sustainable Methodologies and Strategies in School Rehabilitation

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Abstract. This study investigates the importance of rehabilitating school buildings as a sustainable solution to improve teaching conditions, align school infrastructures with contemporary pedagogical requirements, and preserve architectural heritage. The research addresses the challenges schools face, such as structural deterioration, lack of thermal comfort, low energy efficiency, and inadequacy of new educational demands, proposing interventions that integrate sustainability, technological innovation, and architectural flexibility. The methodology critically analyzes specialized literature focusing on sustainable rehabilitation practices and integrating modern technologies in school settings. We considered criteria such as energy efficiency, waste management, and incorporating pedagogical technologies. The priority was identifying solutions that minimize environmental impacts while maximizing interventions' social and economic benefits. The main results highlight that school rehabilitation can reduce operating costs, extend the useful life of buildings, and create more comfortable and inclusive environments for students and teachers. In addition, the use of modern and less polluting materials, associated with up-to-date construction techniques, favors adaptation to environmental standards and the requirements of the twenty-first century. However, challenges such as high upfront costs, technical limitations, and lack of professional training still restrict the implementation of these practices on a large scale. Rehabilitating school buildings is crucial for promoting quality education in sustainable and innovative environments. To overcome barriers and make practical projects feasible, investments in public policies, technical training, and developing specific methodologies tailored to the school context are essential. This rehabilitation process transforms schools into conducive learning spaces and catalysts for urban revitalization and social inclusion, contributing to a more sustainable and equitable future.

Keywords: School rehabilitation; sustainability; pedagogical buildings.

Published by CAUSummit and peer-reviewed under the responsibility of "World Summit: Civil Engineering-Architecture-Urban Planning Congress - CAUSummit-2025".

INTRODUCTION

Cities have undergone profound transformations in the last two centuries in response to technological changes and urban needs[1]. Among the phenomena observed are the aging of urban buildings and the expansion of peripheral neighborhoods. This scenario accentuates the relevance of building rehabilitation, which seeks to conserve heritage and revitalize underused spaces, adding economic and social value[2].

Rehabilitation differs from renovation in preserving the original project and promoting technical and aesthetic improvements with updated and safe materials [1,3]. This practice reduces maintenance costs and promotes compliance with modern safety and energy efficiency standards [4,5]. In addition, it contributes to the appreciation of enterprise, urban revitalization, and modernization, offering sustainable solutions that extend the useful life of buildings[6].

School buildings often experience wear and tear, leading to structural deterioration, thermal discomfort, and insecurity[7]. Rehabilitating these buildings involves making structural repairs, enhancing energy efficiency, and integrating educational technologies to ensure safety and comfort for students and teachers[8,9]. In Brazil and Portugal, public policies prioritize investments in school rehabilitation to improve teaching and learning conditions[10].

Specific methodologies like sustainability assessments allow for effective and innovative interventions integrating social, environmental, and pedagogical aspects. These approaches promote collaboration between engineers, architects, and school managers, ensuring high-quality projects[11,12].

Rehabilitation reduces environmental impacts by minimizing resource consumption and waste generation. Choices of modern, less polluting materials and up-to-date construction techniques are fundamental in this process[13]. One key definition for sustainability includes criteria such as energy efficiency, waste management, and internal environment quality, according to standards such as ISO 15392:2019[14,15].

In addition to the environmental impact, rehabilitation promotes social and economic benefits, such as revitalizing degraded urban areas and real estate appreciation. However, it requires balancing technological innovation and preserving buildings' original characteristics[16,17].

Rehabilitation faces technical and financial challenges, especially in projects that require structural interventions. Adopting advanced technologies and customized methods is essential to ensure effective and economically viable solutions[18,19]. Urban rehabilitation has been a priority in Portugal, given the need to maintain historic buildings and adapt to new environmental requirements[20,21].

Schools need to adapt to the demands of the twenty-first century, balancing innovative technologies, comfort, and sustainability. The school environment should encourage interaction, creativity, and active learning, aligning with changes in student profiles and pedagogical practices[22,23]. Architectural flexibility is crucial to catering to various educational activities and preparing schools for the future[24].

The concept of "school space as a third teacher" highlights the importance of environments that encourage learning and sociability[25,26]. To this end, schools must offer thermal and acoustic comfort, integrate natural elements, and use sustainable technologies, such as solar panels and water reuse systems[27,28].

Rehabilitating buildings, especially school buildings, emerges as an indispensable solution to preserve heritage, promote sustainability, and improve the quality of urban life. Integrating contemporary methods, eco-friendly practices, and responsiveness to social needs enhances buildings and communities.

Critical Review of the Literature on Rehabilitation of School Buildings and Existing Methodologies

The rehabilitation of school buildings is relevant in improving educational spaces' physical, pedagogical, and social conditions. Over the past few years, schools have experienced challenges related to aging infrastructure, lack of energy efficiency, and inadequacy of new pedagogical demands. These factors make rehabilitation essential as a strategy to revitalize buildings and make them better suited to current needs[7].

School buildings have unique characteristics compared to other construction typologies. They are subject to accelerated wear and tear due to heavy use, high user turnover, and the need to meet safety, accessibility, and comfort requirements[8]. Rehabilitating these spaces goes beyond a simple structural adjustment and involves adopting modern, sustainable methodologies aligned with contemporary pedagogical practices.

THE CONTEXT OF SCHOOL BUILDING REHABILITATION

Challenges and Demands

The school infrastructures come from a time when educational demands differed from today's. For instance, the end of the twentieth century saw a significant shift in teaching methods, which required educators to seek more flexible, comfortable, and technology-equipped environments[29]. However, schools still operate in old buildings with inadequate infrastructure to meet the pedagogical and normative requirements of the twenty-first century[30].

Among the main challenges faced by schools are:

- Physical deterioration: Structural wear and tear caused by time and continuous use[7].
- Inadequate environmental conditions: Lack of thermal, acoustic, and visual comfort, hindering learning[9].
- Insecurity and limited accessibility: Structures that do not meet safety and inclusion standards, excluding students with disabilities[22].

Low energy efficiency: Outdated technologies result in excessive energy consumption and high operating costs[6].

The rehabilitation of schools has significant benefits that go beyond the simple modernization of buildings. According to Gnecco[8], structural and environmental interventions in schools improve the safety and comfort of occupants and positively influence educational outcomes. Adequate and well-planned spaces promote greater concentration, productivity, and well-being among students and teachers.

In addition, rehabilitation plays a key role in preserving historic buildings, especially in schools located in urban centers. According to Appleton[21], these interventions must balance the conservation of the original architectural elements with the inclusion of modern technologies, ensuring that the buildings continue to meet educational needs without losing their historical value.

Community engagement is vital in rehabilitation projects to ensure solutions meet local needs and expectations. One effective approach is to hold participatory planning workshops, where stakeholders such as parents, students, and educators can contribute their ideas and priorities to the design process. Gathering input through surveys and feedback mechanisms also helps to align the project with local desires and requirements. Additionally, awareness campaigns are crucial in educating communities about the benefits of sustainable rehabilitation and how it can address their concerns. Collaboration with local professionals, including architects, engineers, and contractors, fosters a sense of ownership and adaptability within the community. Actively involving the community throughout the rehabilitation process increases the likelihood of the project's success and acceptance by those it serves.

Sustainability Concept Applied to School Rehabilitation

Sustainability is one of the pillars we seek in the proposal for this literature review about rehabilitating school buildings. Sustainability is the ability to meet current needs without compromising future generations [14]. In practice, this involves the rational use of resources, the reduction of waste, and the promotion of healthy and efficient environments.

Grijalba-Aseguinolaza and Eizaguirre-Iribar[16] emphasize that sustainability in school rehabilitation extends beyond energy efficiency to include social aspects like inclusion and accessibility. Therefore, sustainable rehabilitation adopts a comprehensive approach that aims to maximize environmental, economic, and social benefits from interventions.

Modern technologies play a transformative role in school rehabilitation projects, making learning environments more efficient, sustainable, and conducive to student success. We compiled a concise list of four key technologies, along with additional elements, seeking the integration of rehabilitation projects.

1. Educational Technologies: Interactive boards, smart classrooms, and integrated digital tools are revolutionizing the teaching-learning process. These technologies create engaging, dynamic learning experiences, fostering greater student participation and understanding.

2. Energy Efficiency Systems: Solar panels, LED lighting, and smart energy management systems reduce operational costs and promote sustainability. Schools can achieve significant savings and reduce their environmental footprint by harnessing renewable energy sources and optimizing energy use.

3. Environment Monitoring Sensors: To optimize learning conditions, schools can implement air quality monitors, thermal comfort sensors, and acoustic panels. These sensors ensure that the indoor environment is healthy and comfortable for students and staff, crucial for effective learning.

4. Sustainable Construction Practices: Utilizing fewer polluting materials and advanced construction techniques ensures long-term durability and minimal environmental impact. Sustainable practices in construction benefit the environment and create safer and healthier spaces for students to learn and grow.

By incorporating these modern technologies, school rehabilitation projects can create more effective, sustainable, and enjoyable learning environments for students, fostering a brighter future for the next generation.

Among the main sustainable strategies applied to the rehabilitation of schools are:

Energy efficiency: Install thermal insulation systems, high-performance windows, and LED lighting[31].

Waste management: Reusing demolition materials and using techniques that minimize waste generation during construction[13].

- Harnessing natural resources: Rainwater harvesting and using natural ventilation systems to reduce dependence on external resources[11].

REHABILITATION METHODOLOGIES

Traditional Methodologies

Traditional rehabilitation methodologies focus on identifying and repairing structural damage, such as cracks, infiltrations, and wear. These methods include visual inspections, in-situ measurements, and laboratory tests to assess the performance of materials[17].

Although these methodologies effectively ensure structural safety, they overlook critical factors like energy efficiency, environmental comfort, and social impact. Kopuz and Bal [19] argue that we should enhance traditional approaches with more comprehensive methodologies to meet the complex demands of school buildings effectively.

Sustainable Methodologies

Sustainable methodologies encompass broader criteria, integrating sustainability principles, energy efficiency, and social impact. Examples include:

- ISO 15392:2019: Guidelines for sustainable buildings, focusing on energy efficiency, water resources management, and waste minimization [14].
- Environmental Certifications: LEED and BREEAM evaluate buildings' environmental and energy performance[32].
- Life Cycle Analysis (LCA): This tool calculates the environmental impacts of each rehabilitation stage, from the choice of materials to the operation of the building[15].

Despite the advances, the literature points to challenges in applying school rehabilitation methodologies. Among them are:

- Lack of standardization: There is no consensus on the criteria to evaluate schools, making it difficult to compare projects and replicate good practices[17]. Sustainable methodologies encompass broader criteria, integrating sustainability principles, energy efficiency, and social impact. Examples include:
- Excessive costs: Sustainable methodologies often require significant investments, making it challenging to apply them in resource-limited contexts, such as in public schools[5].
- Technical capacity building: The lack of professionals trained in sustainable practices and integrated diagnostics limits the efficiency of interventions[12].

The literature review points towards potential opportunities for improvement:

1. Specific methodologies for schools: Tools that consider pedagogical and social demands can make projects more effective and aligned with the needs of educational institutions[10].
2. Professional training: Training in sustainable practices and integrated diagnostics can expand the reach of modern methodologies[11].
3. Technological innovation: Sensors and digital tools used to monitor environmental conditions can optimize the results of interventions[6].
4. Public incentive policies: Government subsidies and funding can enable the adoption of sustainable practices in public and private schools[21].

METHODOLOGIES FOR THE EVALUATION OF SCHOOL BUILDINGS

School buildings play an essential role in forming more equitable and developed societies. They are spaces that house pedagogical practices and directly influence their users' academic performance, comfort, and well-being[7]. Maintaining and modernizing these buildings is crucial, but decision-makers often overlook these efforts. This neglect results in structures that become unsafe, energy-inefficient, inaccessible, and unable to meet current educational needs[8].

Civil engineers and architecture professionals extensively utilize building assessment methodologies to evaluate various constructions' structural, functional, and environmental quality[11]. However, the specific context of schools requires adapting these methodologies to consider unique characteristics, such as the intensive use of spaces, the high turnover of users, and the demands for universal accessibility and social inclusion[22].

This paper examines how to adjust general assessment methodologies, typically used for residential or commercial buildings, to address the rehabilitation needs of school buildings. The focus is on energy efficiency, environmental comfort, accessibility, and sustainability, emphasizing the challenges and opportunities in this adaptation process.

Schools have a different use profile compared to other types of buildings. The constant flow of students, teachers, and staff, combined with the daily use of spaces such as classrooms, corridors, courtyards, and bathrooms, accelerates structures' and finishes' physical wear and tear[7]. Evaluating the school buildings' rehabilitation requires methodologies that accurately assess the durability of materials and propose solutions that minimize long-term maintenance costs[13].

School buildings are not just functional places. Their design focuses on promoting human learning and development. Spatial organization, thermal and acoustic comfort, and indoor air quality directly impact student performance[9]. Thus, evaluation methodologies need to include criteria related to pedagogical adequacy and the well-being of occupants.

Universal accessibility is a key requirement for schools, ensuring that students with disabilities or reduced mobility can fully participate in educational activities[22]. However, general assessment methodologies often ignore these aspects, and it is necessary to adapt them to include specific accessibility criteria, such as ramps, elevators, and adequate signage[33].

GENERAL EVALUATION METHODOLOGIES

Engineers use standard building valuation methods to identify structural issues, assess energy efficiency, and ensure compliance with building regulations. Among the most relevant are: - Visual Inspections: Initial assessment to identify visible damage, such as cracks, infiltrations, and wear[11].

- Life Cycle Assessment (LCA): Method that evaluates the environmental impacts of a building throughout its life cycle, from construction to demolition[33].
- Environmental Certifications: LEED and BREEAM evaluate sustainability, energy efficiency, and natural resource management[32].
- Normative Tools: Standards such as ISO 15392:2019 establish guidelines for sustainable constructions, addressing energy efficiency and rational use of water and materials with low environmental impact[14].

While these methodologies are effective in a significant portion of construction types, their main goals do not meet the specificities of school buildings.

ADAPTATION OF METHODOLOGIES TO THE SCHOOL CONTEXT

The first step in adapting general evaluation methodologies is considering schools' accelerated wear and tear and functional demands. The visual inspections and in situ tests need to be adjusted to include specific criteria, such as impact resistance in high-flow areas (corridors and courtyards) and the durability of surfaces exposed to constant use, such as paintings and furniture[11].

In addition, it is necessary to assess the spatial flexibility of school buildings, ensuring the adaptation of those environments for different pedagogical and technological activities[22].

Energy efficiency is a priority for schools due to the high operating costs associated with the intensive use of lighting, ventilation, and air conditioning. Tools such as LCA and environmental certifications can be adapted to assess schools' energy performance, considering the daily and seasonal use of spaces[33].

Specific measures include:

- High-performance windows should be installed to improve thermal insulation and reduce the need for air conditioning[6].
- Replace lighting systems with LED lamps, which consume less energy and are more durable[32].
- Natural ventilation systems, especially in regions with mild climates, to reduce electricity consumption[13].

Environmental comfort is essential in schools where inadequate lighting, temperature, or acoustic conditions hinder learning. General evaluation methodologies should include specific metrics to measure and improve these factors. Examples include:

- Thermal Comfort: Evaluation of thermal insulation efficiency and air conditioning systems' adequacy[9].
- Acoustic Comfort: Inspection of noise barriers and surfaces that reduce echo and external noise[7].

- Natural Lighting: Verification of using natural light, especially in classrooms, to reduce energy consumption and improve the study environment[33].

To enhance our general methodologies, we must integrate universal accessibility criteria. We must ensure everyone can benefit from our practices by evaluating ramps, elevators, adapted bathrooms, braille signage, and other elements that ensure the full inclusion of all students[22].

Standards such as ISO 21542:2021 can serve as a basis for creating specific school tools, ensuring that buildings meet users' needs with different physical and cognitive abilities[34].

CHALLENGES IN ADAPTATION

The adaptation of general methodologies to the school context faces significant challenges:

Lack of standardization: There is no consensus on the criteria for evaluating school buildings, making it challenging to replicate promising practices[17].

- Excessive costs: Implementing adapted assessment tools may require significant investments, especially in public schools with limited resources[35].

- Technical training: Professionals involved in school evaluation often lack specific training in methodologies that integrate sustainability and inclusion[12].

Adapting general evaluation methodologies to the context of school buildings is essential to ensure that these constructions meet the pedagogical, social, and environmental demands of the twenty-first century. While methodologies such as LCA and environmental certifications offer a solid foundation, they need adjustments to include specific criteria for use, comfort, and inclusion.

The success of this adaptation depends on investments in technical training, the development of specific standards, and government incentives that promote the application of sustainable and inclusive practices in schools. These measures allow the transformation of school buildings into spaces that meet immediate needs and contribute to a more sustainable and equitable future.

DISCUSSION

Given the intensive use of spaces and pedagogical demands, school rehabilitation requires a specific approach. According to Teles[10], it is crucial to adapt methodologies to include pedagogical requirements, such as universal accessibility, integration of educational technologies, and adaptation to public inclusion policies.

Sustainable methodology must go beyond structural and environmental issues, incorporating aspects of usability, thermal and acoustic comfort, and spatial flexibility to meet changes in educational practices[22].

For example, applying energy efficiency assessment tools, such as thermal envelope analysis, is especially relevant in schools, where thermal comfort directly impacts students' concentration and learning[7]. Material reuse and waste management strategies can reduce costs and promote more sustainable practices.

Sustainable methodologies offer a holistic view of rehabilitation, considering energy efficiency, environmental impact, and social well-being[16]. These tools help prioritize interventions and ensure the efficient use of natural resources.

Modern technologies are revolutionizing school rehabilitation projects by enhancing efficiency and sustainability. Interactive boards and smart classrooms are boosting student engagement and learning outcomes. Solar panels and LED lighting are cutting costs and promoting sustainable practices. Environment monitoring sensors, such as air quality and thermal sensors, create optimal learning conditions. Sustainable construction practices using eco-friendly materials and advanced techniques ensure durability and minimal environmental impact. By integrating these technologies, schools create better learning environments for future generations.

In addition, the focus on accessibility and inclusion criteria makes these methodologies appropriate to the school context, promoting spaces that serve all students, including those with special needs[22].

Despite the advances, implementing these methodologies in schools presents significant challenges. The lack of technical capacity to apply sustainability criteria and the scarcity of financial resources are common barriers[17].

Another limitation is the absence of specific school guidelines in available methodologies. Existing tools often focus on residential or commercial buildings, ignoring the peculiarities of educational institutions, such as the intensive use of spaces and specific pedagogical needs[10].

Investing in technical training and implementing public policies to enhance the applicability of these methodologies and promote sustainable rehabilitation is essential. Developing specific tools for schools that incorporate educational and sustainability criteria can also help address the identified gaps.

For example, creating specific indicators to assess rehabilitation's social and educational impact can help managers measure the benefits of interventions. Integrating technologies, such as sensors to monitor air quality and thermal comfort, also represents an opportunity for innovation.

FINAL REMARKS

The rehabilitation of school buildings is relevant, especially in the current context, where the modernization of educational infrastructures has become essential to meet contemporary pedagogical demands. This practice goes beyond simple structural renovation; it is a strategy that integrates improvements in teaching and learning conditions, adaptation to safety standards, environmental comfort, and energy efficiency. By providing more suitable school environments, rehabilitation not only favors the academic performance of students and teachers but also promotes social, economic, and environmental benefits, such as urban revitalization and the creation of inclusive and sustainable spaces.

Sustainability is central to this process, being fundamental to reducing schools' environmental impacts and operating costs. Strategies such as using natural ventilation systems, efficient thermal insulation, and waste management demonstrate how conscious choices can transform schools into efficiency and environmental responsibility models. In addition, a comprehensive approach is indispensable, considering not only structural and energy issues but also social and pedagogical aspects, such as universal accessibility and architectural flexibility, to meet the various educational activities.

Despite the clear benefits, school rehabilitation faces significant challenges. Among them, the high costs, the lack of technical training for implementing sustainable practices, and the absence of standardized methodologies adapted to schools' specificities stand out. Public institutions often face these challenges, as limited resources restrict the scope of their interventions. In addition, the existing methodologies designed for residential or commercial buildings do not consider the peculiarities of intensive use and the pedagogical demands of school environments.

In this context, there are important opportunities for advancement. The development of specific methodologies for schools, which integrate pedagogical, sustainability, and accessibility criteria, is a priority to overcome these limitations. The training of professionals involved in rehabilitation, promoting training in modern practices and integrated diagnostics, can significantly expand the impact of interventions. Incorporating advanced technologies, such as sensors for environmental monitoring and digital tools for performance evaluation, also offers a promising path to optimizing results. In addition, implementing public policies that encourage and finance adopting sustainable practices, especially in public schools, can transform this sector, enabling more ambitious and practical projects.

Rehabilitated school buildings have a profound and lasting impact on student performance and community development. Creating comfortable and modern learning environments enhances academic outcomes by improving concentration, productivity, and overall well-being. Incorporating accessibility features promotes inclusivity, ensuring all students have equitable education opportunities. Improved school infrastructure often catalyzes urban revitalization, attracting investments to surrounding areas and fostering community growth. By integrating green technologies, schools educate students and the community about sustainable practices, raising awareness and fostering environmentally responsible behaviors. Additionally, reduced operating costs and maintenance needs provide economic benefits, allowing schools to allocate resources more effectively and support other critical programs. Rehabilitated school buildings contribute significantly to a brighter future for students and their communities.

Standardizing methodologies for rehabilitating school buildings is essential to ensure consistency and efficiency in the actions conducted. A normative approach will allow the comparison between different projects, facilitating the replication of good practices and integrating sustainable and pedagogical criteria, which is essential to promote school environments that adapt to the demands of the 21st century. With a structured methodology, it will be possible to provide clear indicators to assess the impact of interventions, assisting managers and public policymakers in decision-making. Rehabilitating schools plays a crucial role in promoting quality, sustainable, and inclusive education that meets the needs of future generations.

ACKNOWLEDGMENTS

This work is supported with Portuguese national funds by FCT – Foundation for Science and Technology, I.P., https://sciproj.ptcris.pt/175080UID, DOI 10.54499/UIDB/04082/2020.7

fct Fundação para a Ciência e a Tecnologia

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