SHAPING A RESILIENT FUTURE: SCHOOLS AS EXPERIMENTAL HUBS FOR CLIMATE CHANGE ADAPTATION

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Abstract. In line with European policies for ecological transition, this paper reflects on regenerative architecture as a technical and pedagogical tool to address climate change challenges. The contribution investigates the potential of nature-based solutions as devices for both adaptation and learning, capable of combining environmental sustainability, participation and educational innovation.

The work presents a participatory, replicable and scalable methodology based on the learning-by-doing approach and articulated in four phases: (1) interactive lesson; (2) experiments and field data collection; (3) co-participatory implementation of full-scale interventions; (4) maintenance guidelines. This approach was tested through two case studies: in Cavallerleone (CN), the depaving of urban areas and the development of an infiltration basin regenerated underutilized urban spaces and promoted circular economy practices; in Turin, a Living Wall System installed in the courtyard of the "Pertini" Institute was enhanced as a demonstration device, allowing students to directly measure the microclimatic and air quality benefits.

The results show how collaboration between universities, local administrations and schools generates measurable impacts on the environmental (soil permeability, water management, microclimatic comfort), social (participation and shared stewardship) and pedagogical (development of technical-scientific and soft skills) levels.

The proposed methodology, replicable and adaptable across contexts and age groups, identifies schools as strategic nodes of the ecological transition, capable of combining innovative teaching and urban regeneration, transforming educational spaces into hubs for climate adaptation.

Keywords: Nature-based solutions; Experiential learning; Urban resilience; Climate Adaptation

Introduction

Climate change is no longer a future prospect but a concrete and measurable condition. Recent international reports confirm an average global temperature increase of approximately 1,5°C compared to pre-industrial levels, with the real possibility of reaching +2,8°C by the end of the century in the absence of effective mitigation and adaptation measures (UNEP, 2025). This phenomenon has a significant impact on the urban environment, where building density and soil impermeabilization amplify the effects of heatwaves, extreme rainfall and air pollution. At the same time, the construction sector continues to contribute substantially to global greenhouse gas emissions, accounting for more than 37% CO_2 emissions per year (UNEP, 2022).

Within this context, the concept of urban resilience assumes a strategic importance in the framework of European policies for ecological transition. The European Green Deal (2019) and the EU Climate Adaptation Strategy (2021) outline the need for cities able to adapt to climate change through sustainable and integrated solutions, promoting the active involvement of local communities and citizens in the co-design of resilient spaces. The recent Nature Restoration Law (2024) further reinforces this vision, introducing binding targets for the restoration of urban and peri-urban ecosystems.

In line with these objectives, this paper reflects on regenerative architecture as a technical, pedagogical and social tool capable of fostering co-design practices and experiential learning. Through the direct engagement of schools, considered as true laboratories for resilience, the contribution investigates the educational and transformative potential of nature-based solutions, laying the foundations for a multidimensional approach to urban sustainability.

Nature-based solutions as climate change adaptation strategies

Nature-based solutions, defined by the European Commission (2021) as "actions inspired and supported by nature", represent a promising approach to addressing urban environmental challenges through strategies that enhance ecosystem processes. More than simple "greenspace", these solutions are the result of deliberate planning, design and management, capable of addressing environmental and social challenges simultaneously, including climate change adaptation, protection of biodiversity and improvement of human well-being.

Among the different types of nature-based solutions, living wall systems are among the most promising technologies for reducing urban heat islands and improving air quality, offering measurable benefits. Recent studies show that such systems can reduce the external walls surface temperature by up to 9°C during the summer months (Vox et al., 2018) and contribute to lowering the surrounding air temperature by 1,8-3,3°C (Tabatabaei & Fayaz, 2023), significantly mitigating the urban heat island effect. Moreover, these solutions have proven effective in reducing air pollutants, with the capacity to sequester between 1,5 and 2,3 kg of CO_2 per square meter per year (Bernardo et al., 2025). Beyond measurable outcomes, vertical greenery systems have been shown to improve psychological and physical well-being and the urban spaces perception, reducing stress and promoting a sense of community belonging (Pérez-Urrestarazu et al., 2017; Sadick & Kamardeen, 2020).

Another type of nature-based solution widely recognized for its effectiveness in urban climate adaptation is the rain garden and related infiltration basins. Integrated into the urban structure or open spaces of public buildings, these systems play a key role in sustainable stormwater

management, reducing surface runoff and mitigating flood risks in highly impermeable urban areas.

According to the Swedish Environmental Protection Agency (2022), rain gardens are among the priority solutions for climate adaptation, as they combine the ability to regulate water flows with the development of microhabitats and socially valuable spaces. On average, they can retain around 63% of incoming stormwater volumes, reducing runoff peaks during intense rainfall events (Sabbagh et al., 2025). Furthermore, the progressive infiltration of water into the soil supports groundwater recharge and improves water quality through natural phytoremediation processes.

In addition to their thermal and hydrological effects, the aesthetic and educational functions of these solutions make them ideal tools for the regeneration of school and community spaces: the active involvement of students and citizens in their design and maintenance fosters environmental awareness and encourages community participation in sustainable territorial management.

Schools as laboratories for resilience

Due to their educational function and civic role, schools represent privileged spaces for experimenting with climate adaptation practices and social innovation. In urban contexts, they can be understood as micro-infrastructures of proximity, often characterized by underutilized courtyards with large paved and unshaded surfaces, which contribute to local overheating and thermal discomfort (Cordeiro et al., 2025). Their reactivation through the introduction of nature-based solutions not only improves microclimatic comfort but also promotes educational and community processes oriented toward sustainability.

Several studies demonstrate that the presence of green spaces within schools is associated with improved cognitive performance, reduced stress levels and enhanced student well-being, highlighting the strong connection between the environment and academic performances (Browning & Rigolon, 2019). Within this framework, schools can become true laboratories of urban resilience, where scientific knowledge is intertwined with hands-on experimentation.

Previously documented experiences further support this perspective by showing how experiential learning around nature-based solutions can effectively translate complex environmental processes into accessible educational practices. Researchers at the University of Porto, for instance, developed a hands-on activity for primary and secondary school students focused on constructed wetlands, demonstrating how their direct involvement in the construction and testing of small-scale nature-based systems fosters a deeper understanding of water cycles, pollution mitigation mechanisms and ecosystem services, while encouraging environmental responsibility beyond the local scale (Almeida et al., 2024). Similarly, the Living Green Infrastructure Lab model promoted by Texas A&M University highlights the value of interdisciplinary and site-based learning activities, in which students actively participate in the design, construction and monitoring of green infrastructure, strengthening the students' ability in relating theoretical knowledge to spatial, ecological and technical dimensions (Tao et al., 2019).

Furthermore, the adoption of learning-by-doing approaches fosters the acquisition of both technical and scientific skills, as well as soft skills such as teamwork and creative thinking (Montacchini et al., 2025), integrating academic knowledge with low-impact self-construction and co-design practices. In this sense, school buildings operate as open learning devices, capable of regenerating underutilized spaces and strengthening collective awareness toward ecological transition.

Methodology: participatory learning construction sites

Within this framework, a methodology was developed to communicate scientific knowledge in an accurate yet accessible and engaging way for children and young people. Designed to be both replicable and scalable according to different educational levels, the methodology is based on the direct involvement of students in experiential learning activities. The entire process unfolds through progressively interactive and participatory steps:

Step 1. Interactive lesson;

Step 2. Experiments and field data collection;

Step 3. Co-participatory implementation of a full-scale intervention;

Step 4. Guidelines for maintenance and long-term care.

Step 1 – Interactive lesson

The activity begins with an introductory session and general presentations aimed at creating a relaxed and open classroom atmosphere, breaking down traditional teacher–student hierarchies. The aim is to foster an environment in which students feel free to express themselves and learn through both direct instruction and trial-and-error, while maintaining mutual respect.

This is followed by an informative and awareness-raising moment on climate change, explaining its causes, effects and impact on daily life, as well as on nature-based solutions as concrete tools for climate adaptation and the development of resilient cities. In order to ensure engagement, a core knowledge, that is necessary to master the subject and understand the reasons behind the subsequent experiments, is conveyed through images, videos and the direct involvement of students in explaining and defining concepts, with the pace of discussion guided by the students' interests.

Step 2 – Experiments and field data collection

After the theoretical foundation is established, students engage in hands-on experiments.

Through a comparative experiment, they analyze two urban models: one with impermeable surfaces (such as asphalt and concrete) and one with permeable surfaces (such as soil, sand and vegetation). By pouring the same amount of water on both, students observe what happens: how much water is absorbed, how quickly it penetrates the subsoil or whether stagnation occurs, gaining a tangible understanding of how natural solutions can act in rainwater management.

Then, using a thermal camera, they explore the concept of albedo and the

cooling effect of plants through evapotranspiration. Students are asked to measure the temperatures of different surfaces (asphalt, grass, plastered wall, green wall), interpret the obtained images and compare collected data, developing a tangible comprehension of material behavior under solar radiation.

These activities allow students to experiment firsthand and consolidate the concepts previously discussed.

Step 3 – Co-participatory implementation of a full-scale intervention

The third phase focuses on the application of acquired knowledge through the implementation of a full-scale climate adaptation measure.

This measure may involve the development of a brand-new solution or participation in an ongoing construction site.

In the former, students actively co-design and build a micro-NBS through participatory learning workshops, integrating educational activities, design experimentation and field communication. Using recycled materials and native plant species, these interventions also promote circular economy practices, reduce the consumption of raw materials and encourage the enhancement of local resources. Students play an active role in the micro-NBS co-production process, designing, selecting plant species, assembling structures and participating in post-installation care.

In the latter case, after observing and analyzing more technical or potentially dangerous construction site activities, which involve the use of professional equipment such as jackhammers or small excavators, students engage directly in the final stages. Here they contribute to the planting of native plant species and the final arrangement of the area.

These actions allow the practical and educational dimensions to be integrated, consolidating acquired knowledge and reinforcing awareness of the collective value of regenerated spaces.

Step 4 – Guidelines for maintenance and long-term care

Finally, following the completion and handover of the projects, a phase of user empowerment is initiated. Having actively participated in the design and implementation stages and acquired both theoretical and technical knowledge of the installed micro-NBS, students are now able to maintain them over time. To this end, simple shared maintenance guidelines are developed, dealing with irrigation methods, plant and material condition monitoring and site cleaning practices, ensuring the long-term maintenance of the interventions' performances.

This phase, conceived as an integral part of the educational process, represents a transfer of responsibility from expert to user, enabling students to recognize that environmental resilience requires continuity, care and a sense of belonging. It also raises awareness of maintenance as a civic act, promoting collective responsibility in the management of common spaces.

Case study 1: a co-participatory urban transformation process in Cavallerleone (CN)

The experience carried out in the municipality of Cavallerleone (CN) represents a significant example of participatory urban regeneration, developed within the framework of the call "Percorsi di Sostenibilità" – Measure 3 "Biodiversity and reconnection with the natural environment", promoted by the CRC Foundation. The project, titled "Verde in Comune", aimed to improve the environmental quality and resilience of the municipal area through concrete actions of requalification and sustainability education, actively involving local community and, in particular, primary school children.

The activity with the students was developed in three complementary phases, designed to build an educational and experiential path that combined scientific dissemination, field experimentation and project implementation.

The first phase, which was informative and workshop-based, took place at school and aimed to introduce the concepts of climate change and nature-based solutions, understood as strategies capable of providing both environmental and social benefits in the urban context. Through accessible language and simple experiments, students explored the principles of climate change mitigation and adaptation. After watching a short introductory video, they conducted basic experiments: measuring the surface temperatures of different materials with a thermal camera to understand the urban heat island effect and simulating water infiltration in permeable and impermeable soils using pre-built models. These activities allowed them to directly understand the importance of reducing asphalted surfaces and increasing green surfaces to improve microclimatic regulation and urban drainage.

The second phase involved moving from theory to practice through the de-paving and greening of traffic islands in Piazza Santa Maria, in the centre of the village. After the removal of surface rocks and bituminous layers, with the support of municipal technical staff and teachers, the children participated in soil preparation and the planting of native and low-water-demanding species, such as Festuca arundinacea, Hypericum perforatum and Rosmarinus officinalis prostratus, transforming a previously impermeable area into a small green corridor.

The third phase focused on the construction of an infiltration basin in Via Monasterolo, designed to collect and filter rainwater from surrounding impermeable surfaces. The intervention represented a concrete application of circular economy principles, as the rocks removed from the traffic islands, during de-paving, were reused as drainage material for the new basin, symbolically closing a cycle of reuse within the same project.

For safety reasons, it was not possible to involve the students in the intermediate stages of excavation and laying of drainage layers due to the technical complexity and the use of heavy machinery. However, they actively contributed during the final stage, planting native species selected for the basin.

Overall, the Cavallerleone experience demonstrated how collaboration

among municipal administrations, schools and universities can generate a participatory urban transformation laboratory, where concrete climate adaptation actions can be tested, transforming technical experimentation into a collective process of learning and urban regeneration. Beyond reducing impermeable surfaces, improving natural drainage capacity and increasing urban biodiversity, the initiative carried strong educational value, helping students understand the ecological and social significance of regenerating small public spaces, restoring identity and function to often neglected areas of the city.

Case study 2: enhancement and analysis of a living wall system in Turin

The second case study concerns the experience carried out at the Sandro Pertini Comprehensive Institute in Turin, where, in June 2025, a living wall system was installed. The wall was donated by the Japanese company Nitto, main sponsor of the ATP Tennis Finals, as a sign of gratitude to the city of Turin for hosting the sporting event. The installation was placed in the large courtyard of the Pertini Institute, chosen for its proximity to the Inalpi Arena, the venue of the tournament, and for its layout: a large but mostly asphalted and underused space. The introduction of the green wall therefore represented both a symbolic and functional intervention in terms of climate and spatial regeneration. For this reason, the municipality, in collaboration with the school administration and the university, wanted to enhance the installation by transforming it into an educational and experimental opportunity to help students understand the environmental and social value of a nature-based solution integrated into the urban environment.

The activity involved second-year middle school classes and aimed to teach students about the functioning of a living wall system, its benefits and the scientific principles behind it. The intervention was structured into two modules, designed according to a participatory and hands-on learning methodology.

During the first module, held in the classroom, students were guided through an interactive discussion on climate change issues and related adaptation measures. Through videos, images and thought-provoking questions (e.g. "Why is there a green wall in your school?"), key concepts, such as urban heat islands, evapotranspiration and air quality, were introduced using simplified but scientifically rigorous examples and data. A brief overview of different green wall typologies was also presented, ranging from hydroponic systems to modular substrate-based solutions, through references to existing green walls in Turin, to make the topic more tangible and relatable.

Special emphasis was placed on the role of vegetation in passive cooling and pollutant absorption, highlighting how vertical greenery contributes to mitigate urban heat and improving the liveability of public spaces.

The second module took place directly in the school courtyard, in front of the installed green wall, where students engaged in a series of guided scientific experiments designed to observe and measure the benefits of the system in a tangible way.

Using a thermal camera, they measured the temperatures of different surfaces (asphalt, wall, green wall), recording and discussing the obtained data. This experience allowed them to understand how materials react to solar radiation and how the plants' evapotranspiration process contributes to cooling the surrounding air.

Subsequently, an experiment on air quality was proposed. Using a simple white handkerchief, the students "cleaned" the leaves of the living wall system and observe how the tissues became dirty due to the accumulation of dust and smog residues, providing concrete evidence of the plants' capacity to capture atmospheric pollutants typical of the urban environment.

Finally, to explore soil permeability and stormwater management topics, students were divided into three groups and tasked with constructing a soil model inside a plastic bottle, simulating three different types of soil: one impermeable, one moderately permeable and one highly draining, varying the composition of layers (gravel, soil, sand, and cement). By pouring the same amount of water into each model and timing the infiltration time, students were able to empirically verify the importance of permeable surfaces for sustainable rainwater management.

The experience contributed to the reactivation of an underused school space, transforming it into a permanent environmental education laboratory. The green wall not only improves the microclimatic comfort of the courtyard but also provided a starting point for concretely exploring themes of sustainability and urban resilience.

Through collaboration among the school, university and local administration, the project demonstrated how educational institutions can become catalysts for environmental innovation, places where concrete climate adaptation strategies are tested and a new collective awareness is fostered. As in the Cavallerleone case, the school once again confirms its role as a strategic place for climate-adaptive urban transformation, an active site of learning, research and sustainable regeneration.

Results and discussion

The results obtained from the Cavallerleone and Turin case studies demonstrate how collaboration among universities, local administrations and educational institutions can generate measurable impacts on environmental, social and pedagogical levels.

In Cavallerleone, the de-paving intervention and the development of an infiltration basin increased permeable surfaces and enhanced stormwater management capacity, rehabilitating underused areas while introducing circular economy practices through the on-site reuse of removed materials. The involvement of students in the final planting stages encouraged the acquisition of operational and long-term maintenance skills, translating concepts such as permeability, drainage and biodiversity into concrete learning experiences.

In the Turin case study, the green wall installed at the Pertini Institute served as a demonstrative device: experiments on surface temperatures, air quality and soil permeability made the microclimatic benefits of nature-based solutions tangible, while contributing to the partial reactivation of a

large but predominantly asphalted school courtyard.

Overall, the multidimensional approach adopted improved the ecological and environmental performance of the sites, strengthened intergenerational collaboration and promoted the development of both technical-scientific competencies and soft skills among students. In this perspective, schools emerge as laboratories for resilience, learning and experimentation environments that can disseminate replicable models of urban climate adaptation.

Conclusion

The experiences described demonstrate how the integration of experiential learning with academic technical know-how and low-impact construction techniques can transform schools from mere places of education into a driver of environmental and social innovation. The activities carried out in the two case studies show that the combination of dissemination activities, field measurements and full-scale implementations can activate processes of regeneration in underutilized public spaces, improving their microclimatic and hydrological performances and generating collective awareness of climate adaptation and mitigation issues.

In line with the European Green Deal's objectives on decarbonization, urban resilience and environmental education, this paper proposes a replicable and scalable methodology for climate education based on the learning-by-doing principle. Within this framework, schools act as demonstrative devices for the application of nature-based solutions as tools for climate change adaptation, promoting the development of widespread skills and a sense of responsibility in the long-term care of regenerated spaces. Schools therefore emerge as strategic hubs for the climate-adaptive urban transformation, capable of generating tangible environmental impacts while raising informed and aware citizens.

The transferability and scalability of this method across different age groups and urban contexts suggest its replicability as a standard local climate adaptation strategy, with prospects for long-term performance monitoring and the expansion of the approach to school networks and wider urban systems, thus strengthening the link between innovative education and ecological transition.

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Figures

Figure 1a – Experiential learning activities in Cavallerleone (CN) – Thermal camera measurements.

Figure 1b – Experiential learning activities in Cavallerleone (CN) – Soil permeability experiments.

Figure 2 – Children active participation in the de-paving intervention in Piazza Santa Maria in Cavallerleone (CN).

Figure 3a – Soil permeability experiment. Development of the impermeable soil model.

Figure 3b – Soil permeability experiment. Testing the permeability properties of the three types of soil.











DECISION SUPPORT TOOLKIT IN EARLY DESIGN PHASE: A LIVING WALL SYSTEM FOR GREYWATER TREATMENT AND REUSE IN MOUNTAIN ENVIRONMENT

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Abstract. Mountain regions are increasingly affected by seasonal droughts driven by shifts in precipitation patterns and rising average temperatures, which are sometimes accompanied by peak tourist seasons, placing significant pressure on local water resources and infrastructure. This study presents a conceptual framework for a tool to guide the design of a nature-based solution (NBS) for water management: a Living Wall System (LWS) for greywater treatment and reuse in mountain environments. The aim of the study, which is part of the Nature-based Solutions for Mountain Villages (NBS4MOV) project, is to provide a solid groundwork for a decision-support tool to be used during the early design phase and to promote and facilitate the adoption of the proposed LWS in a replicable and scalable way. A performance-based design methodology is adopted to integrate water management, engineering, and architectural needs, as well as specific requirements for a LWS in the complex mountain environment where operational constraints are more pronounced. First, the architectural features to be considered during the early stages of the integrated LWS design process are identified. Then, a selection process defines transportability, modularity, replicability, scalability, and reversibility as key needs for system development. To systematically develop the decision support tool, for each identified need, corresponding requirements are defined and linked to performance specifications to guide implementation. The envisioned system is intended to be accessible and effective for non-expert users by collecting technical and performance-related data indirectly. Finally, a dedicated matrix is developed to manage a wide range of information and to enable performance data to be evaluated in relation to each other. The output is presented as a structured system of questions with related rules, enabling the generation of a report containing design guidelines, technical specifications for each category, and relevant warnings.

Keywords: performance-based approach, decision-making tool, living wall system, mountain valleys;

Introduction

Seasonal droughts are becoming more frequent in mountainous areas due to changes in rainfall patterns and rising average temperatures (Ioan, 2025), often exacerbated by periods of high tourist activity, which strain local water supplies and infrastructure (Rogowski, 2025). Moreover, although demographic decline linked to limited services and economic opportunities continues to affect remote mountain villages, the recent expansion of digital infrastructure and remote work models offers new scenarios for repopulation and socio-economic revitalisation of these areas (Polin et al., 2024). Given these considerations, effective water resource management is essential to promote tourism development and repopulate mountain areas while ensuring the hydrogeological safety of these territories. Nature-based Solutions (NBS) can significantly contribute to this objective by providing multiple ecosystem services, including local water treatment (Pereira et al., 2023). Within this framework, the NBS4MOV project (2023-2025) aimed to prototype and install an NBS system for greywater treatment. The outcome was a first prototype of a modular stand-alone Living Water System (LWS) for the treatment and local reuse of domestic greywater, excluding wastewater from toilet flushing, based on the most recent literature on this emerging technology (Pucher et al., 2025; Prodanovic, 2025; Masi, 2025). The project highlighted the importance of involving both professionals responsible for NBS design and implementation, as well as non-technical users. However, it also revealed that initial interactions with a professional team could act as a barrier for private individuals or local administrators due to perceived economic and commitment-related constraints. Therefore, there is a clear need for tools that facilitate the initial assessment and decision-making process, allowing users to estimate and plan solutions tailored to their specific needs and the characteristics of the installation sites. In the context of NBS, existing tools designed to support urban climate adaptation planning are primarily targeting technical users such as urban planners, engineers, and environmental specialists. Moreover, current tools often require substantial technical knowledge to navigate effectively, creating barriers for non-expert users (Voskamp, 2021).

Considering the above, the work presented in this paper represents the early stages of developing a decision support tool as part of the NBS4MOV project. The primary aim is to explore and analyse how a non-expert user could identify appropriate system performance requirements without directly engaging with complex technical methodologies or possessing specialized expertise. While technical users can define needs and performance goals directly, this work focuses on conceptualizing how the tool could be made accessible and effective for non-expert users as well. The proposed tool is intended to provide access to technical information for both user types and is being developed using a performance-based design approach, which is particularly valuable given the high complexity of mountain environments. To manage a wide range of information and enable comparative performance evaluation, a dedicated matrix structure has been conceptualized with defined performance categories. The intended functionality would allow each user interaction to trigger the automatic extraction of one or more design requirements, which would then be compared with similar ones within the same performance category. In conclusion, the tool could enable access to technical information for both technical and non-technical users, thus potentially facilitating the dissemination and adoption of the proposed LWS for water management in mountain villages. The envisioned system would support context-sensitive solutions by accounting for needs that vary according to geographical location and site-specific conditions. Future development