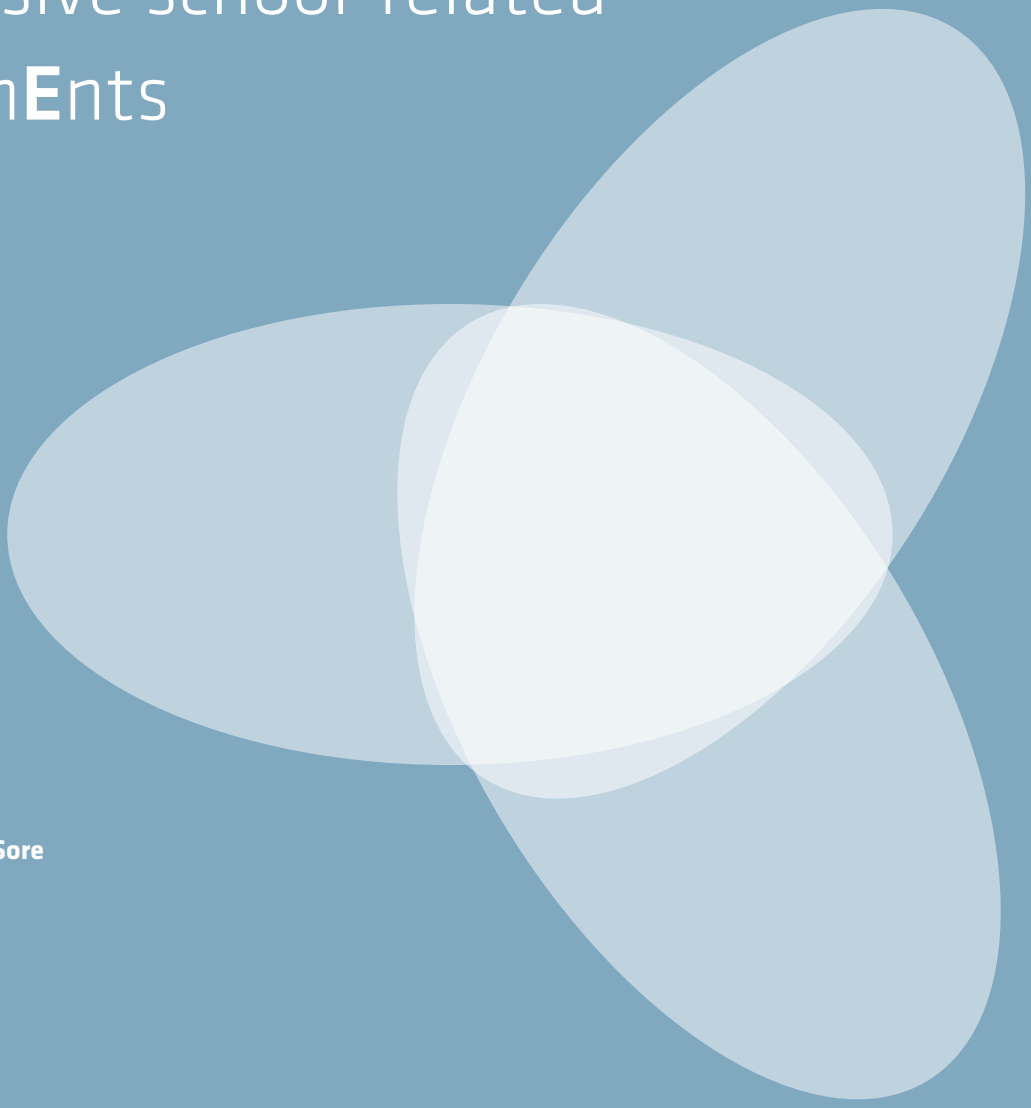
UNIVERSITÀ DEGLI STUDI FIRENZE

Da un secolo, oltre.

REACTIVE

Framework for the design of **R**esilient, h**E**althy, **ACT**ive, and **I**nclusive school-related en**V**ironm**E**nts



PhD Candidate: Antonia Sore

Tutor: Prof. Rosa Romano

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DOTTORATO DI RICERCA IN
Sostenibilità e innovazione per il progetto dell'ambiente costruito e del sistema prodotto

CICLO XXXVI

COORDINATORE DEL DOTTORATO Prof. Paola Gallo

RE-ACTIVE - Framework for the design of Resilient, hEalthy, ACTive, and Inclusive school-related enVironmEnts

Settore Scientifico Disciplinare ICAR/12

Dottorando
Dott. Antonia Sore

(firma)

Tutore
Prof. Rosa Romano

(firma)

Referente del curriculum
Prof. Leonardo Zaffi

(firma)

Anni 2020/2025 *(di inizio e fine corso)*

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Abstract

As urban areas face increasing climate and environmental pressures, this thesis investigates the schoolyard as a strategic micro-urban space to promote climate resilience, public health, and physical activity. Seventy percent of cities globally are already experiencing the consequences of climate change, with proven harmful effects on both urban ecosystems and human health due to extreme weather events, air pollution, and heatwaves (Heaviside et al., 2017). According to the WHO, a rise in heat-related deaths is expected in urban areas. At the same time, cities face other overlapping challenges, including rapid urbanisation, resource depletion, and the loss of biodiversity, all of which threaten the quality of urban life and public space (Gebalska, 2017).

Children, in particular, represent one of the most vulnerable groups due to their physical sensitivity and limited capacity to adapt to environmental stressors (WHO, 2017). **This research, therefore, places children at the center of its investigation, recognizing their unique developmental needs and the importance of environments that support their well-being.**

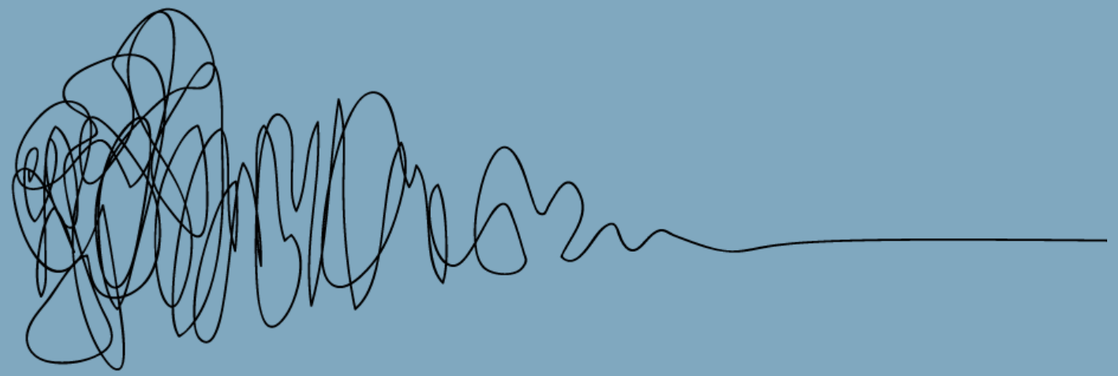
In cities where access to public green and livable areas is limited, schoolyards represent valuable assets that offer unique opportunities to test and promote regenerative solutions for climate change mitigation and adaptation, capable of reducing localized climate hazards.

Taking climate and other environmental stressors as a design challenge, **the thesis adopts a layered and systemic approach to explore how schoolyards can be transformed into climate-resilient, inclusive, and health-supporting environments.** Through the lenses of climate adaptation, child health and development, and active design, the research explores the potential of schoolyards to address multiple risks while offering co-benefits to students, educators, and surrounding communities.

In addition to examining schoolyards as standalone spaces, the research also explores their role within the wider urban and neighborhood fabric. **Shifting the focus to children's overall experience of everyday commute from home to school, the research examines the surrounding micro-urban spaces that are part of children's daily school experience, such as streets, entrances, waiting areas, and pedestrian paths.** This perspective informs **the development of a multi-scalar audit tool, structured around three interconnected scales: the schoolyard, the school premises, and the neighborhood**. By considering these spatial relationships, the thesis aims to capture the full range of environmental factors that influence children's health, activity, and resilience.

The results are synthesised into a comprehensive and practical toolkit designed to guide municipalities, schools, and practitioners in transforming schoolyards into resilient, health-promoting spaces that foster learning, child development, and climate action.

Keywords: Climate Resilience, Schoolyards, Urban Health, Active Design, Child Health and Wellbeing



Preface

This thesis is the result of a journey that began with a research fellowship and a strong personal and professional commitment to the themes of sustainability, climate resilience, public health, and urban environments that promote health and physical activity.

The opportunity to conduct this research emerged within the framework of a research fellowship at the Interuniversity Research Centre ABITA, where I was involved in several regional and European projects related to climate resilience, urban health, and sustainable design on both building and product scale. I developed this doctoral thesis in parallel with my project responsibilities, shaping it progressively through real-world practice, interdisciplinary collaboration, and field-based inquiry.

The non-linear nature of this process brought both challenges and unique opportunities. It allowed me to ground theoretical reflections in concrete experiences and to continuously adapt the research focus in response to evolving knowledge and needs within the field. This setting shaped not only the research questions but also the methodological approach, ensuring a constant dialogue between academic inquiry and applied research.

I am deeply grateful to the individuals and institutions who supported me along the way, particularly my supervisors and colleagues who believed in the value of this work even when its path was not yet clearly defined.

I hope that the reflections and results presented in this thesis will contribute to the growing discourse on climate-resilient, health-promoting urban environments – and, above all, support those working to reimagine not only schoolyards but all public spaces in our cities as places of care, learning, and resilience.

Antonia Sore
Florence, 9th July 2025

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Outline of the PhD Dissertation

In the context of accelerating climate change and rising urban health inequalities, children represent one of the most vulnerable population groups. This doctoral research examines how outdoor spaces – specifically schoolyards and adjacent micro-urban environments – can be reimagined to simultaneously improve climate resilience, promote health, and support child development through an integrated design framework.

The thesis is grounded in a transdisciplinary approach, intersecting themes of climate adaptation, public health, child development, and environmental design. Its primary objective is to develop a scientifically grounded yet practical framework that supports the design of schoolyards and school-related environments into climate-resilient, healthy, and active spaces. The structure of the thesis is organized in six interconnected parts, each building upon the previous one to guide the research from problem identification to solution development:

Part I – Background and Challenges
The opening part frames the societal and scientific challenges related to climate change, public health, and child well-being in cities. It identifies children as a vulnerable group and schoolyards as micro-urban environments, key urban spaces that have untapped potential in addressing climate and health issues.

Part II – Literature Review
The second part explores scientific literature across the core themes identified in Part I: climate resilience (including mitigation and adaptation), health and well-being, and child development. This section reviews state-of-the-art knowledge to extract key indicators and criteria for quality, climate-resilient, healthy, and active schoolyards.

Part III – Best Practices Analysis
The third part analyzes exemplary international and local case studies to identify successful design strategies, implementation processes, and enabling policies. It concludes with a comparative analysis of the existing transformation projects and initiatives, toolkits, and methodologies, bridging research with operational tools that inform the development of the new framework.

Part IV – REACTIVE Framework Development
This section presents the scientific basis, methodology, and structure of the newly developed REACTIVE Framework. It reflects on the principles, indicators, and design logic behind the proposed tools, ensuring methodological transparency and reproducibility.

Part V – Conclusions & Future Research
The thesis concludes by summarizing key findings, evaluating the scientific contribution of the research, and suggesting areas for future study and refinement of the proposed framework.

ANNEX – REACTIVE Toolkit
The annex presents the main output of this PhD research: REACTIVE Toolkit. Designed as an operational and ready-to-use resource it is tailored to support public administrations, practitioners, and researchers in the transformation and design of school-related environments into climate-resilient, health-promoting, and inclusive spaces.

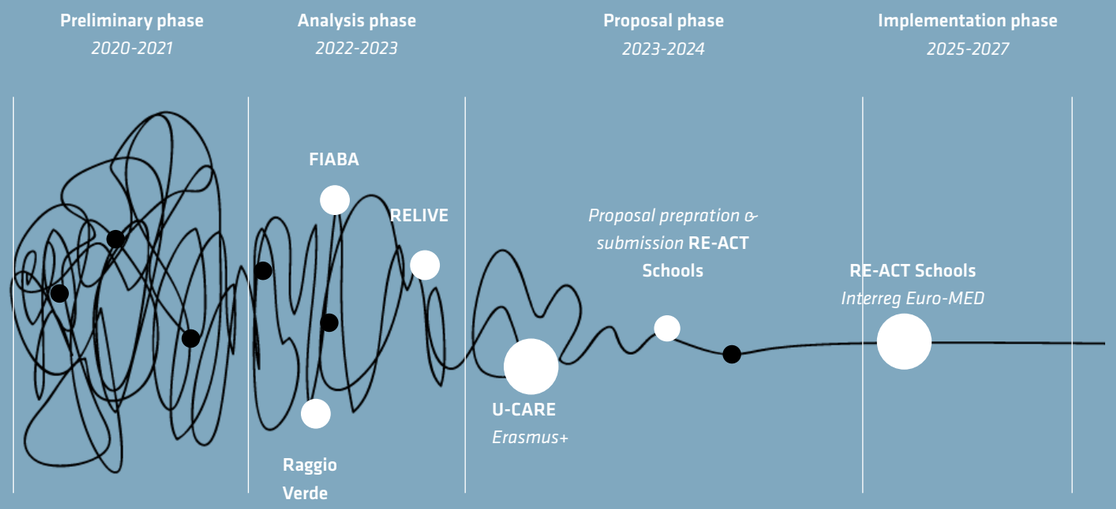
Scope and Key Terms

The doctoral thesis examines the relationship between environmental stressors (including climate change, pollution, and habitat loss) and child health, well-being, and development in urban settings.

While this research initially focused on schoolyards as spaces for climate adaptation, it has evolved into a broader inquiry into school-related environments Therefore, the term "**school-related environments**" used throughout the thesis refers not only to schoolyards but also to the surrounding micro-urban spaces that are part of children's daily school experience, such as streets, entrances, waiting areas, and pedestrian paths. The core spatial unit remains the schoolyard, but it is approached as part of a wider, interconnected system.

Furthermore, the term "**child/children**" refers to individuals between 0 and 17 years of age, as defined by Article 1 of the United Nations Convention on the Rights of the Child (UNCRC, 1989).
"*A child means every human being below the age of eighteen years unless under the law applicable to the child, majority is attained earlier.*" Article 1, UNCRC, 1989.

Lastly, in the context of this research, "**hazards**" are defined as environmental or spatial conditions, either natural or anthropogenic, that may pose risks to children's health, development, or well-being. This definition is adapted from the Intergovernmental Panel on Climate Change (IPCC, 2023) and tawilored to the urban and design-based focus of this research, emphasizing hazards that can be addressed through site-scale adaptation strategies.



Bibliographic review: Delimitation of the scientific problem and definition of the research scope.

Critical analysis & synthesis of the state of the art: Definition of the analytical basis for developing the research proposal.

Development of the REACTIVE Framework based on the analytical results, including refinement of indicators in the context of the U-CARE project and the first experimental applications within the Interreg RE-ACT Schools proposal.

Initial applications and validation and future development within the RE-ACT Schools project.

Legend: ● Research projects supporting the doctoral research theme ● Research projects

Introduction

I. Scientific collocation of the research

I.a. Scientific-disciplinary areas involved in the research

REACTIVE research is situated within the scientific-disciplinary area of Civil Engineering and Architecture (Area 08), with the Technology of Architecture (ICAR / 12) being the relevant scientific-disciplinary sector.

I.b. Scientific-disciplinary sectors engaged in the research

Due to its multidisciplinary nature, the research also involves other scientific disciplines: Urban Planning and Design (ICAR / 20) and Industrial Design (ICAR / 13).

II. Background

II.a. State of the art: reference framework and field of investigation

The research began with an investigation into the impact of climate change on citizens' health and well-being. The World Health Organization estimates that more than 23% of global deaths are attributable to modifiable environmental factors, such as air pollution, poor water quality, and extreme weather events (Prüss-Ustün et al., 2016). In urban settings, these risks are amplified by high population density, pollution, and infrastructure that often lacks resilience to climate hazards (EEA, 2018; IPCC, 2022).

The research further expanded its scope, recognizing that a complex interplay of environmental, spatial, and social factors shapes urban health. These include access to clean air and water, thermal comfort, mobility and accessibility, exposure to biodiversity, and contact with nature, all of which are linked to improved physical and mental health (WHO, 2016; Frumkin et al., 2017; Nieuwenhuijsen, 2021). Equally important are social cohesion, community belonging, and active lifestyles supported by the urban form. The built environment can either promote or hinder these factors by enabling or discouraging physical activity, social interaction, and healthy behaviors (Giles-Corti et al., 2016; WHO Regional Office for Europe, 2023).

From a vulnerability perspective, scientists highlight that children are among the most affected groups by environmental and climatic stressors. Due to their developing physiology, higher breathing rates, and behavioral exposure patterns, children are more sensitive to threats such as air pollution, extreme heat, limited access to nature, and sedentary lifestyles (UNICEF, 2021; EEA, 2022; Etzel et al., 2024; IPCC, 2022). These factors not only compromise immediate well-being but also impact lifelong health trajectories by influencing respiratory function, emotional regulation, and cognitive development (Landrigan et al., 2018; WHO, 2017).

Within this context, the research places children at the center of its investigation, responding to the call for child-sensitive climate adaptation and urban policy (UNICEF, 2021; IPCC WGII FAQ 3, 2022). Reflecting on the urban environments that most influence child development and well-being, schoolyards emerge as critical but underutilized public spaces. These spaces represent one of the few places where children spend time daily, are governed by public institutions, and are present within communities (Dyment & Bell, 2008; Green Schoolyards America, 2021). Despite this potential, most schoolyards remain paved, ecologically barren, and poorly integrated into broader urban resilience or health agendas (Kelz et al., 2015; EEA, 2022).

Later in the research, the scope was extended to encompass school-related environments, including adjacent streets, thresholds, and neighborhood infrastructure, to capture the full extent of the urban settings that shape children's daily experience, exposure, and development opportunities.

II.b. Delimitation of the scientific problem

Following the literature review, the main knowledge gaps on climate resilience, child health and wellbeing, and the schoolyard's role were highlighted:

- While urban design literature increasingly addresses climate adaptation, public health, or education independently, few frameworks integrate these dimensions holistically at the scale of schools and schoolyards (Baró et al., 2022; Dessì & Fianchini, 2022; Sanz-Mas et al., 2023; van den Bogerd et al., 2021).
- Current evaluation tools in climate resilience and health rarely focus on child-centered outdoor environments such as schoolyards, creating a gap between implementation and measurable impact (Díaz-Martínez et al., 2022; Gallez et al., 2024; Mygind et al., 2022; van den Bogerd & Maas, 2021).
- Even though children are widely recognized as highly vulnerable to climate-related and environmental stressors (IPCC, 2022; UNICEF, 2021; WHO Europe, 2023; EEA, 2022), school environments are largely overlooked in climate adaptation and health promotion. Research consistently highlights the benefits of outdoor play and access to nature-rich environments for children's health, well-being, and cognitive development (WHO, 2016; Ginsburg, 2007; Gascon et al., 2015). However, schoolyards often lack in ecological quality, thermal comfort, and developmental affordances (Antoniadis et al., 2022; Flax et al., 2022; Lanza et al., 2022; Sanz-Mas et al., 2025; van den Bogerd et al., 2021).

Therefore, REACTIVE research focuses on developing a framework to support the transformation and design of schoolyards into climate-resilient, healthy, and active environments, offering a systemic and design-driven contribution to this specific yet strategic typology of public space.

II.c. Sources

A wide array of scientific and grey literature (publications, articles, reports, Ph.D. theses, etc.) from different academic fields on the topic of climate change, health, urban health, and active design (with a focus on the promotion of physical activity in urban environments) was consulted during the preliminary investigation to gain a deeper understanding of the research landscape and to support the development of a systemic perspective on the problem. As the research evolved, sources related to child development and school environments, in particular schoolyards, were further explored to deepen the understanding of age-specific needs and design opportunities. Furthermore, European research projects and best practices were analyzed to validate the adopted methodology and identify KPIs to parameterize the final results.

III. Aim and objectives of the research

III.a. Aim of the research

The general objectives of REACTIVE research are:

- Respond to the urgent need for climate-resilient and health-promoting urban environments that support children's development and active lifestyles.
- Reframe the concept of a schoolyard by focusing on its potential as a strategic micro-urban environment.
- Investigate the interconnections between climate change, health, and schoolyard design from a child-centered perspective.
- Identify design strategies and systemic solutions for transforming schoolyards into multifunctional, inclusive public spaces.
- Define a set of indicators and criteria to assess the environmental, social, and developmental performance of schoolyards at multiple scales.

III.b. Objectives of the research

The specific objectives of REACTIVE research are:

- Conduct a structured review of literature and international practices on schoolyards, focusing on their role in supporting climate resilience, health, child development, and physical activity.
- Analyze schoolyard transformation best practices through the lenses of climate adaptation, health promotion, and child development.
- Develop a structured, multi-scalar, and interdisciplinary framework to guide the design, evaluation, and transformation of school-related environments into resilient, healthy, and active places.
- Support knowledge transfer that enables the adaptation and testing of the toolkit in future European pilot actions.

IV. Research methodology, tools, and research activities

The preliminary phase of the research consisted of progressive investigations aimed at circumscribing the field of inquiry and delimiting the scientific problem. This was followed by the analysis of a repertoire of best practices to compare approaches, methodologies, and solutions currently available for creating climate-adaptive and health-promoting urban environments. The knowledge acquired through these phases was synthesized into a structured framework, which includes the research methodology, a multi-scalar audit with indicator sets, design guidelines, and a co-design kit for designing and transforming school-related environments.

IV.a. Preliminary phase

- Acquiring knowledge capable of reconstructing the national and international state of the art on innovations related to climate resilience, health, child development, and physical activity.
- A collection of literature on:
  - Climate Change and its implications for Health, Urban Health, Health and Child Development,
  - Climate Resilient Design and Active Design principles
  - Existing strategies and KPIs related to Health and Climate Adaptation in public space

IV.b. Analysis phase

- Comparative analysis of schoolyard transformation best practices
- Identification of key design elements, indicators, and recurring barriers
- Development of thematic matrices linking environmental risks, child health, and design interventions

IV.c. Proposal phase

- Drafting of the REACTIVE Framework
- Creation of an indicator-based audit method for assessing climate and health risks
- Creating practical REACTIVE Toolkit

IV.d. Future implementation phase (planned)

Framework testing is outside the current PhD timeframe. However, future implementation and validation will be carried out through the Interreg Euro-MED project RE-ACT Schools, which was recently approved, where the toolkit can be applied to pilot schoolyards.

The RE-ACT Schools project (2025–2027), funded under the Interreg Euro-MED Programme, builds directly on the outcomes of this research and will enable real-world testing, adaptation, and validation of the developed framework in multiple Mediterranean schoolyards.
This phase will provide essential feedback on the framework's usability and performance, supporting its refinement through participatory evaluation processes. It also opens up new directions for research, including the digitalization of the toolkit and the extension of the methodology to other urban microenvironments.

V. Results: scientific relevance, innovation, and usefulness of research

The research synthesizes scientific literature across climate change, public health, urban design, and child development to formulate a child-centered, interdisciplinary framework for designing schoolyards as climate-resilient, inclusive spaces that enhance health and well-being (IPCC, 2022; UNICEF, 2021). This framework intentionally bridges urban design, climate adaptation, and developmental science, offering practical and contextually grounded guidance.

By aligning with the IPCC Sixth Assessment Report, which highlights the urgency of safeguarding children, this approach ensures relevance to current climate risks (IPCC WGII FAQ 3, 2022). It is further reinforced by the European Environment Agency, which advocates for integrated social and ecological interventions, such as greening school infrastructure, to increase urban resilience and equity (EEA, 2022).

By adopting a multi-scalar and systemic approach, the research analyzes schoolyards through multiple lenses to explore which spatial strategies can simultaneously address environmental, health, and social challenges. Findings are synthesized into a practical framework designed to support cross-disciplinary knowledge sharing and practical application in urban school contexts.

In detail, research proposes a practical, interdisciplinary response to climate and health challenges in cities by:

- Reframing schoolyards as everyday public spaces with untapped potential for climate resilience, well-being, and child development
- Bridging disciplines to deliver a practical, evidence-based design toolkit
- Providing methodology and indicators to support decision-makers, designers, and researchers

VI. Target groups and spendability of study

Thetarget groups of the research are public administrations, municipalities, educational building owners, practitioners, and researchers involved in urban transformation, climate adaptation, and architecture design, as they hold the strategic, technical, and/or operational responsibility for shaping school-related environments and translating evidence-based insights into actionable policies, designs, and interventions.

VII. Possible future research developments, limits, and open questions

The current research does not include direct implementation, and its evaluation component will be addressed in forthcoming applied research projects.
Future research developments involve the digitalization of the framework for designing and evaluating integrated design solutions for urban regeneration and design. REACTIVE research and framework can be further expanded by studying other urban trends that impact the sustainability of the built environment, creating an integrated vision for the future of sustainable cities with a comprehensive set of strategies and solutions for sustainable development.

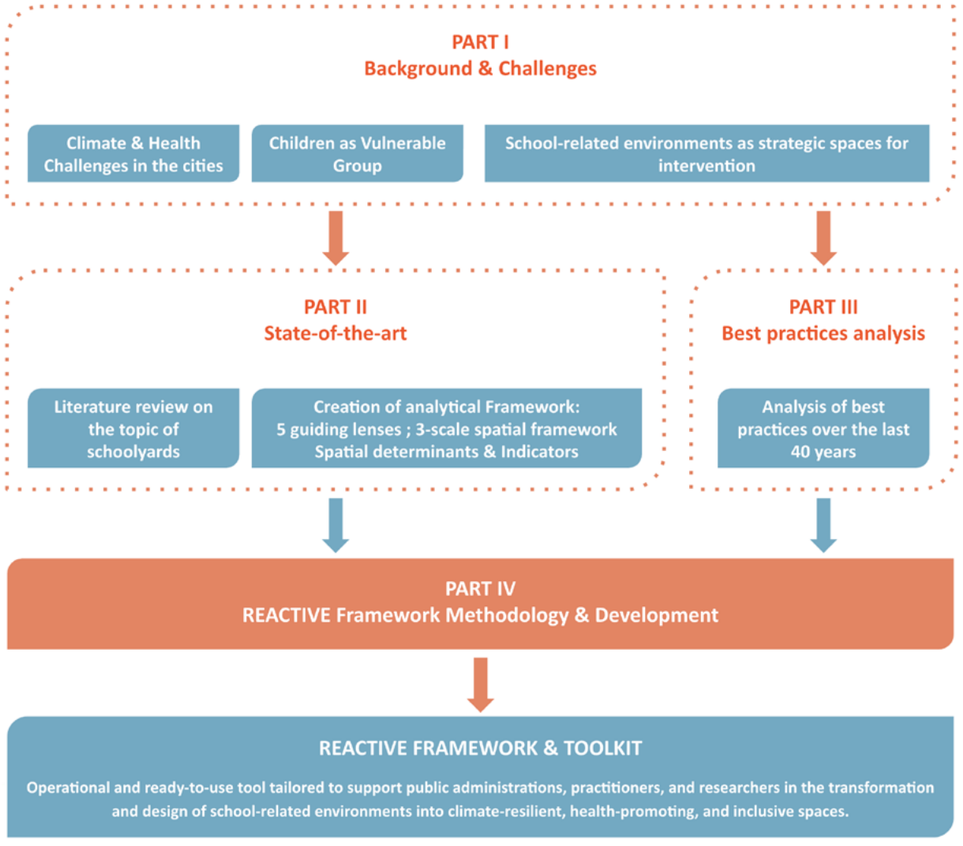
Furthermore, the research results can be implemented in the HORIZON 2020 calls dedicated to climate change and the New European Bauhaus, which aim to develop process and product innovations.

VIII. Research outline

As shown in the figure below, the structure of this thesis is organized to build a clear progression from conceptual foundations to an operational output.

Part I introduces the background and challenges, framing the climate and health issues in cities, with a focus on children as a vulnerable group and school-related environments as strategic intervention spaces. Part II synthesizes the state of the art by combining a literature review with the development of an analytical framework comprising five guiding lenses, a three-scale spatial framework, and defined determinants and indicators. Part III applies this framework to analyze best practices from the last 40 years. These insights inform Part IV, in which the REACTIVE Framework methodology and logic are explained.

The research findings are collected in an operational REACTIVE Framework & Toolkit, designed as a ready-to-use resource for practitioners, policymakers, and researchers.



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PART I -

Framing the challenge & the research context

The first part of the thesis lays the research context. Focusing on environmental hazards and health vulnerabilities, it introduces children as a target group and schoolyards and school-related environments as urban spaces capable of addressing pressing climate and environmental challenges within cities.

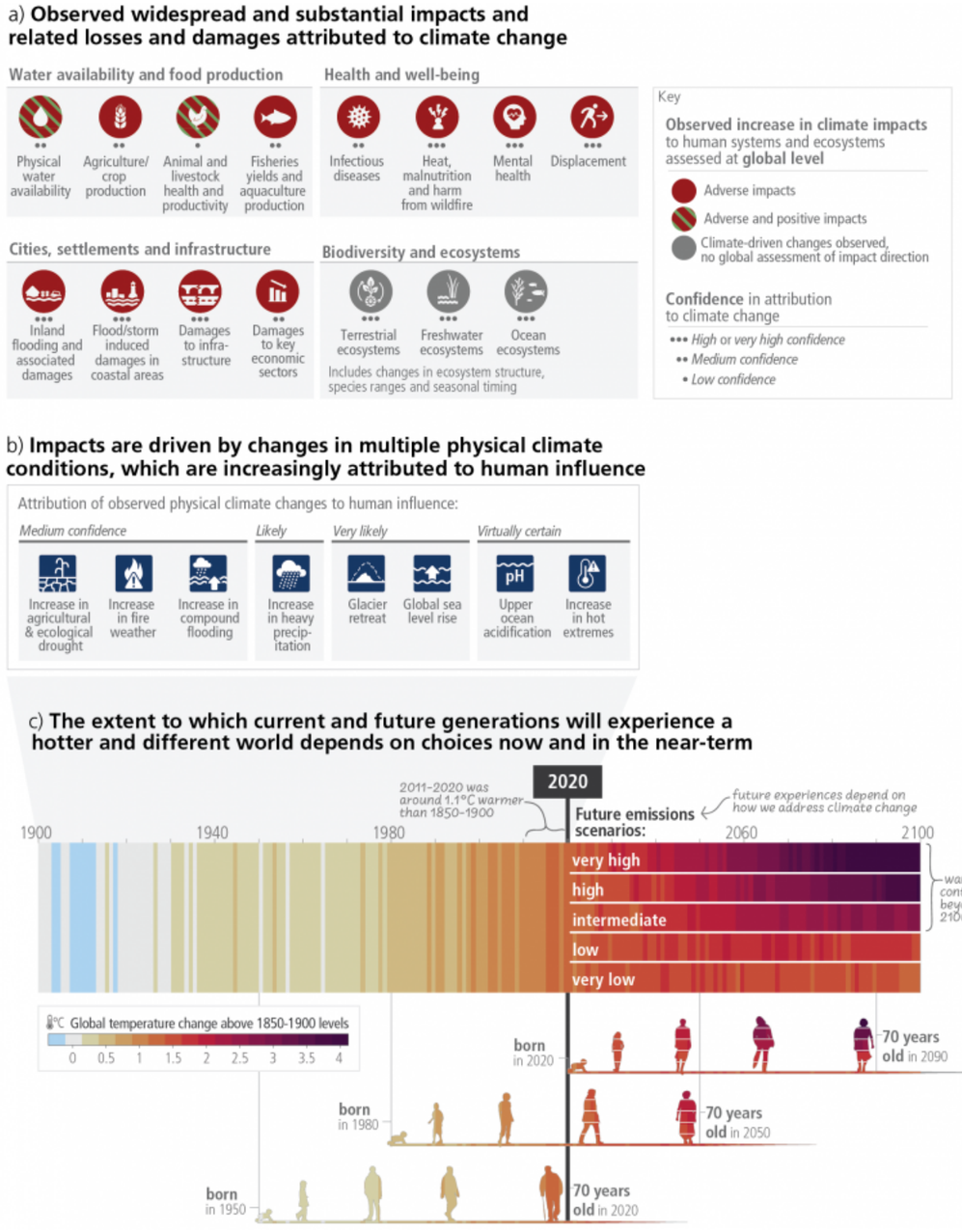


Figure 1.1. *Observed adverse impacts of human-caused climate change on systems critical for health and well-being, including food security, water access, cities, and biodiversity. The extent and intensity of these impacts are increasingly attributed to anthropogenic emissions. Source: IPCC Sixth Assessment Report, Synthesis Report, 2023.*

1. The Urban Challenge in the Anthropocene

1.1. Understanding the Urban Challenge in the Anthropocene

We are living in the Anthropocene– a geological era in which human activities, especially urbanization, resource consumption, and greenhouse gas emissions, are profoundly reshaping Earth's ecosystems and climate systems (Crutzen, 2002; Steffen et al., 2015). Among these transformations, climate change has emerged as one of the most pressing challenges of the 21st century, with far-reaching consequences for planetary systems and for the health and well-being of all living beings.

The IPCC Sixth Assessment Synthesis Report (2023) highlights how climate change is already disrupting food and water security, damaging infrastructure, accelerating biodiversity loss, and amplifying risks to human health. The adverse effects of climate change on human health are multifaceted, ranging from increased risk of vector-borne diseases due to general temperature changes to direct and indirect effects on physical and mental health, particularly through extreme weather events (Heaviside et al., 2017). As illustrated in Figure 1.1. the risks that future generations will face depend on the emission pathways and policy choices we make today.

In cities, the effects of climate change are further amplified by localized physical conditions, such as the Urban Heat Island Effect (UHI) and Stormwater Runoff, which are shaped by land use, materials, vegetation, and urban form. Approximately 70% of cities worldwide are already experiencing severe climate-related impacts, driven by more frequent and severe extreme weather events (Watts et al., 2023; WHO, 2021; UN-Habitat, 2022). In dense urban contexts, climate change impacts also interact with other environmental stressors, such as air pollution and biotope loss, creating compound and cascading risks that are more complex and difficult to manage (IPCC AR6 Synthesis Report, 2023; EEA 2019).

As a result, people living in cities face layered and disproportionate risks due to their biological vulnerability, high exposure to climate-related hazards and environmental stressors, and often limited adaptive capacity (Ebi & Semenza, 2008). According to the United Nations, around 55% of the global population currently lives in urban areas, totalling over 4 billion people. This number is expected to rise to 68% by 2050; therefore, reducing both the causes and exposures to these stressors is a priority for urban planning, public health, and overall global sustainability efforts (United Nations, 2018; IPCC, 2022).

In this evolving and complex urban context, the environments in which people live and interact have an increasingly critical role in shaping health and well-being. Extreme temperatures and precipitation, air pollution, noise, and biotope loss, among others, are widely recognized as key determinants of health (Watts et al., 2023). Addressing these interconnected risks requires holistic, systems-based approaches capable of managing complexity. In this regard, design has the potential to transform these pressures into opportunities to reimagine the environments we inhabit and to reduce the negative impacts of current and future hazards.

1.2. Climate-related hazards and Environmental stressors in cities

Understanding the pressures to which people in cities are exposed and their interdependencies is a necessary step toward analysing risks and identifying opportunities for action.

Following the European Environment Agency report (EEA, 2019), this work adopts the terms **climate-related stressors**, dependant on changes in the climate system (extreme temperatures, flooding, and droughts), and **environmental stressors**[1], which are outcomes of the physical, chemical, or sensory properties of the built environment (such as air pollution, noise pollution, water pollution, and biotope loss[2]).

The health impacts are multiple and range from physical health problems such as respiratory diseases and cardiovascular illnesses to cognitive development and emotional well-being (WHO, 2016; Nieuwenhuijsen et al., 2017; Gascon et al., 2015). The following Table 1.2. provides an overview of climate-related and environmental stressors and related key health implications

Table 1.2. Overview of the Climate and environmental stressors and related key health implications.

Stressor Type	Specific Stressor	Possible health implications	References
Climate-related	**Extreme temperatures (heat, solar radiation)**	Increases the risk of cardiovascular and respiratory illnesses	EEA, 2019; WHO Europe, 2017; WHO, 2021; Zhao et al., 2017; Nie et al., 2024
	Extreme precipitation (flooding)	Increases the risk of waterborne diseases; exacerbates existing health problems	Du et al., 2010; WHO Europe, 2017; Ebi et al., 2020
	Droughts	Impacts water availability, increases heat-related illness risk	Sorensen et al., 2022; WHO Europe, 2017; Ebi et al., 2020
Environmental	**Air pollution**	Linked to asthma, cancer, and premature death	WHO, 2021; ISGlobal, 2024; WHO Compendium, 2024; EEA, 2019
	Noise pollution	Impacts sleep, learning, and cardiovascular health	Stansfeld & Matheson, 2003; EEA, 2020; WHO, 2018; WHO Compendium, 2024
	Biotope Loss	Affects mental health, reduces opportunities for physical activity	Frumkin et al., 2017; Gascon et al., 2015; WHO, 2016; IPBES, 2019; UNEP, 2020; EEA, 2019
	Inadequate infrastructure for active mobility, play, and sport	Increases the risk of obesity and cardiovascular diseases	Sallis et al., 2016; Giles-Corti et al., 2016; WHO, 2016; WHO Compendium, 2024; ISGlobal, 2024

1 In this thesis, climate-related stressors refer to climate hazards as defined by the IPCC (2022): physical climate-related events or trends such as heatwaves, flooding, or drought. Environmental stressors, in line with the European Environment Agency (2019), denote non-climatic environmental factors that can strain or harm human health and ecosystems, including air and noise pollution, loss of green space, and degraded environmental quality.

2 In this thesis, biotope loss is introduced as an environmental stressor, as it undermines essential ecosystem services for human health and well-being (EEA, 2019; IPBES, 2019; UNEP, 2020).

1.3. Risk, Vulnerability, and the IPCC Framework

To systematically address interconnected climate change threats, the Intergovernmental Panel on Climate Change (IPCC) provides a robust framework for **understanding climate change risks**. The IPCC defines **climate risk** as the interaction among **hazards** (e.g., heatwaves, flooding, air pollution), **exposure** (e.g., children in outdoor urban settings), and **vulnerability** (e.g., sensitivity and limited capacity to cope).

The most recent IPCC AR6 report expanded the framework to include **responses** – recognizing that adaptation and mitigation strategies can **either reduce or exacerbate risks** (IPCC, 2022; IPCC, 2023). Given the complexity of the interrelationships among stressors, human health, and well-being, the thesis adopts the IPCC AR6 risk framework to examine health, focusing on **how climate hazards, environmental stressors,** and **vulnerabilities converge in specific environments.**

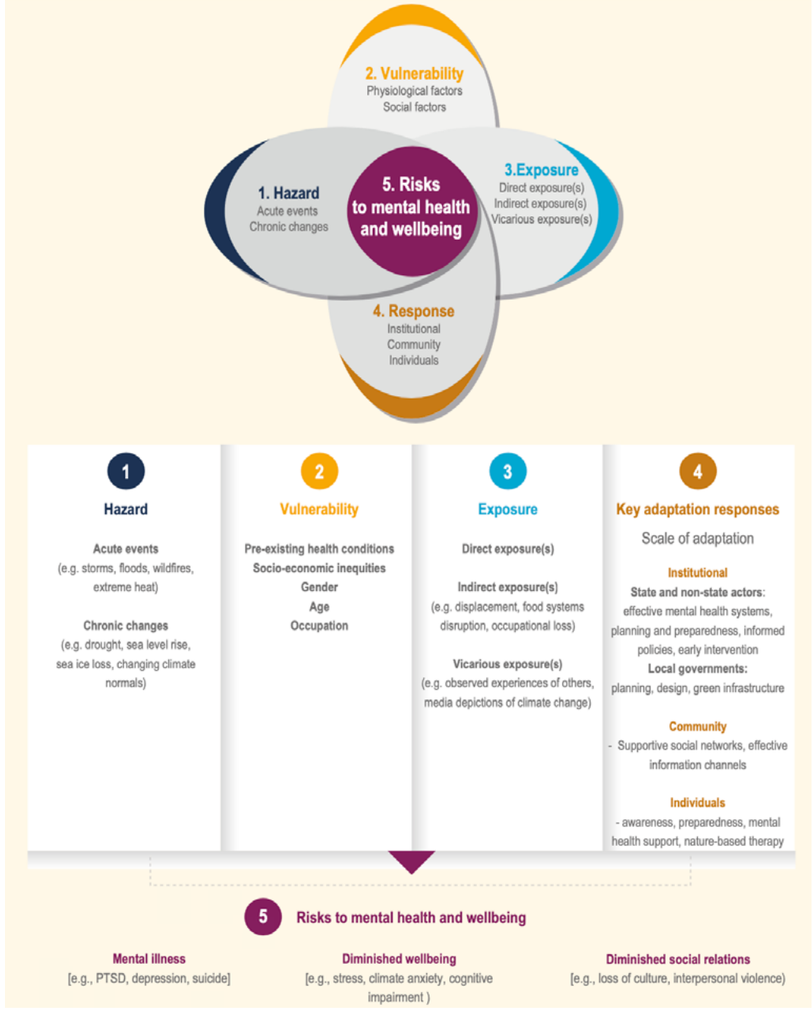


Figure 1.3.b Climate change impacts on mental health and well-being and key adaptation responses. The IPCC AR6 Risk Framework conceptualization. Source: IPCC Sixth Assessment Report, Synthesis Report, 2023.

1.4. Health as a Priority in Global Policy Agendas

In response to the growing urgency and complexity of climate- and environment-related health risks, international and regional policy agendas are increasingly acknowledging the interconnections between climate change, urbanisation, and public health, calling for innovative, holistic approaches to addressing these challenges.

Over the past decade, several global policy frameworks, such as the IPCC's Sixth Assessment Report and WHO's Health in All Policies (HiAP), have recognized the need to integrate public health objectives into mitigation and adaptation strategies (Table 1.4). These reports showcase the paradigm shift: urban planning must integrate environmental sustainability and health resilience as interdependent goals.

Table 1.4. *Global and Regional Frameworks Linking Climate, Health, and Urban Adaptation*

Framework/Policy	Focus	Relevance to Urban Health and Climate Change Adaptation
Paris Agreement (2015)	Limit global warming to well below 2°C	Recognizes adaptation needs in vulnerable systems like cities; indirect health co-benefits
2030 Agenda – SDGs (2015)	17 Sustainable Development Goals, including SDG 3 (Health) and SDG 11 (Cities)	Promotes healthy, inclusive, resilient cities and universal health access
New Urban Agenda (2016)	Sustainable and inclusive urban development	Emphasizes urban health, green public spaces,and social equity
IPCC Sixth Assessment Report (2022)	Scientific consensus on climate risks, vulnerabilities, and adaptation needs	Calls for transformative urban adaptation to reduce systemic health risks
WHO Health in All Policies (HiAP)	Mainstreaming health across all sectors and policies	Advocates for health-oriented planning and decision-making
WHO Global Strategy on Health, Environment & Climate (2019)	Reducing environmental health risks and enhancing system resilience	Prioritizes climate-resilient health systems and healthy urban environments
European Green Deal	Achieve climate neutrality by 2050; cut GHG emissions by 50% by 2030	Supports air quality, mobility, and green infrastructure for healthier cities
EU Climate Adaptation Strategy (2013 and 2020)	Enhance resilience to climate change across sectors	Framework for local adaptation planning, including urban health
European Climate Law (2021)	Makes climate adaptation a legal obligation	Encourages climate-health integration, though gaps remain
Sendai Framework for Disaster Risk Reduction (2015–2030)	Reduce disaster risk and losses in lives, health, and livelihoods	Links urban climate risk to health outcomes and resilience planning
WHO Manifesto for a Healthy Recovery from COVID-19 (2020)	Promotes recovery through healthy environments, clean energy, and mobility	Supports climate-smart healthcare and active urban lifestyles
WHO Urban Health Initiative	Helps cities assess and implement interventions on air pollution and climate	Promotes integrated approaches to reduce urban environmental health risks
UN Framework Convention on Climate Change (UNFCCC)	Global agreement on climate mitigation and adaptation	Recognizes public health as a key consideration in urban resilience
Global Covenant of Mayors for Climate & Energy	City-level commitment to integrated climate and energy action	Grows focus onthe health outcomes of urban mitigation and adaptation strategies

From a health impacts perspective, the World Health Organization defines adaptation as "designing, implementing, monitoring, and evaluating strategies, policies and programmes to manage the risks of climate-relevant health outcomes" (WHO, 2014), emphasizing the importance of a systems-based approach to managing climate-related health risks.

The global and regional frameworks presented in Table 1.4 provide the foundation for action; however, their impact ultimately depends on how policies will be translated into tangible urban adaptation strategies, as illustrated in Figure 1.4., ultimately influencing the adaptive capacity.

Furthermore, to ensure equitable and inclusive adaptation measures, urban policies increasingly emphasize the need to prioritize vulnerable groups, including children, older adults, and low-income populations, as well as people with disabilities, visually impaired individuals, pregnant women, outdoor workers, athletes, and displaced persons. These populations are disproportionately affected by both climate-related and environmental stressors.

Adaptation, therefore, is not only about building resilient infrastructure but also about addressing social inequalities and increasing co-benefits, with health among the most critical aspects.

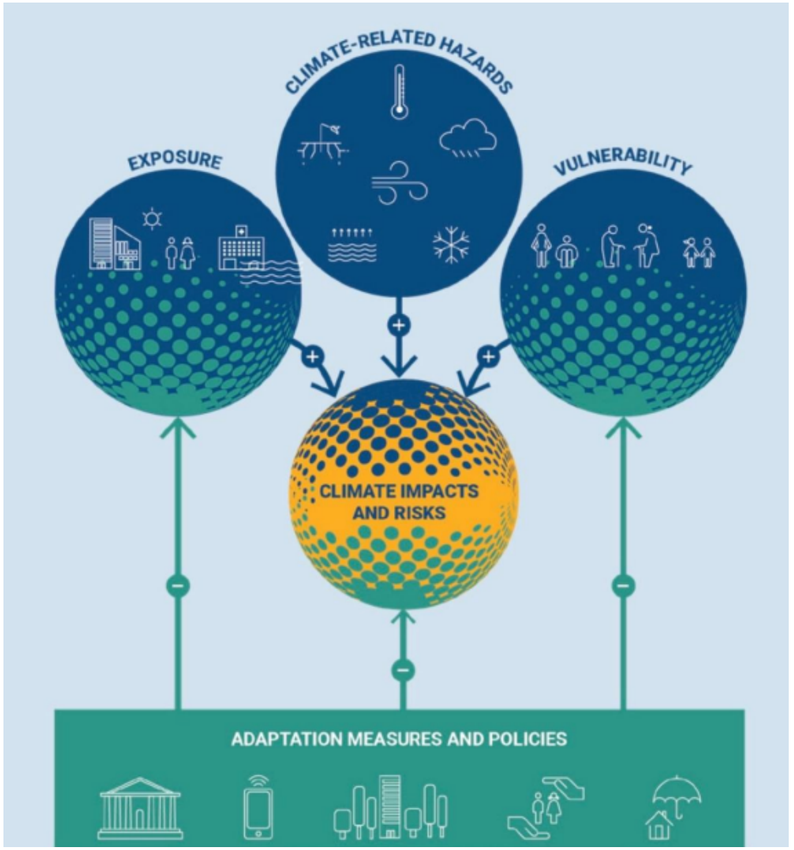


Figure 1.4. Components of climate risks showing where adaptation policies and measures fit in to increase overall climate resilience by reducing exposure or vulnerability. Source: Climate ADAPT.

1.5. Embedding 'health' as a key component of the climate adaptation strategy

Integrating health into climate adaptation policies is essential to address the vulnerabilities and exposures identified by the IPCC risk framework.

While cities offer a wide range of social, economic, and cultural benefits, people living in cities are also especially vulnerable due to dense living conditions, limited green infrastructure, and the UHI effect. Figure 1.5. shows the multiple interconnections of climate change and human health. Climate change affects health both directly (heat waves, cold waves, floods, storms, droughts, and wildfires) and indirectly through ecosystem impacts, such as biodiversity loss and air pollution. The direct impacts of climate change also lead to socioeconomic effects and losses, which in turn, further aggravate human mental health and well-being (European Commission, 2020).

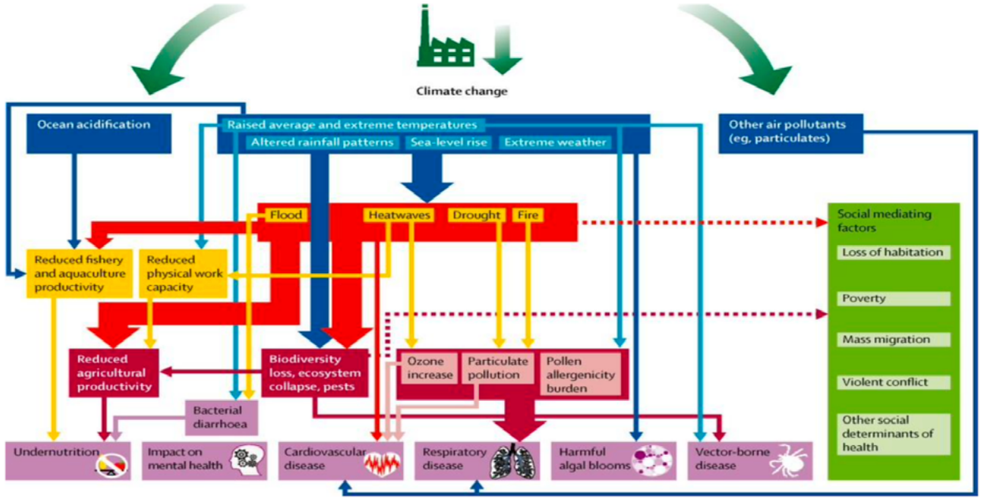


Figure 1.5. The pathways between climate change and human health. Source: European Commission, 2020.

At the same time, cities are not only vulnerable to climate change but also significant contributors to it. Urban areas consume more than two-thirds of global energy and account for over 70% of greenhouse gas emissions (UN-Habitat, 2020). Both mitigation (reducing emissions) and adaptation (reducing adverse impacts) are essential to effectively reduce the negative effects on the environment and health. Integrating health-centered adaptation strategies with low-carbon urban planning, such as promoting active mobility, energy-efficient buildings, and green infrastructure, improves both urban resilience and contributes to global climate mitigation goals.

Integrating climate-related aspects into EU and National policies has so far focused on climate surveillance, preparedness, and early warning and response systems. Taking a preventive approach (rather than focusing only on disaster preparedness and risk reduction) and including a wide range of policies (such as land use, housing, building design, and infrastructure) is key to achieving long-term, resilient, and healthy environments.

1.6. Vulnerable Populations in Urban Settings

According to the IPCC risk framework, the impact of climate hazards depends on exposure and vulnerability. Certain groups are more at risk because of their health, living situations, or the spaces they use in the city. As previously mentioned, the vulnerable population includes children, the elderly, people with chronic diseases, and other groups at increased risk, as shown in Table 1.6 (IPCC, 2023; EEA, 2019).

Table 1.6. Vulnerable Populations in Urban Settings, the reasons for their heightened vulnerability, and the most urgent climate and environmental risks they face. Highlighting these priority needs supports targeted adaptation and public health interventions, in line with the IPCC risk framework.

Vulnerable group	Key factors
Children	Sensitive to heat and pollution, due to their ongoing physical and mental development
Older adults	Declining ability to regulate body temperature and often presence of chronic illnesses
People with chronic diseases	Health worsened by air/temperature changes
Low-income populations	Often live in high-risk, resource-poor areas
Pregnant women	Sensitive to heat, dehydration, and pollution (affects fetus too)
Outdoor workers	Direct exposure to adverse weather effects for long hours
Athletes	Prolonged outdoor exertion to adverse weather effects
Homeless/displaced people	Lack of basic shelter/protection

In line with the IPCC's risk framework, these groups often face greater exposure to hazards and lower adaptive capacity, thereby amplifying their overall vulnerability. For example, children's developing bodies and behaviour patterns (such as outdoor play) increase both their exposure and sensitivity to environmental risks (Nie et al., 2024; WHO, 2021). By understanding and addressing the unique vulnerabilities of each vulnerable group, cities can develop innovative, climate-resilient, and health-promoting environments that benefit the wider community.

From a long-term perspective, supporting children's health is also an important investment in their future. By protecting children and creating environments where they can grow up healthy, we help prevent chronic health issues as they age. This life-course approach also reduces the risks they face as older adults, creating long-term benefits for society (European Commission, 2020; WHO Europe, 2017).

As cities respond to the challenges of climate change and environmental stressors, adaptation strategies must prioritize the needs of vulnerable populations to ensure just and adequate health protection. This approach not only advances health equity but also maximizes the impact of interventions by addressing those most at risk (IPCC, 2023).

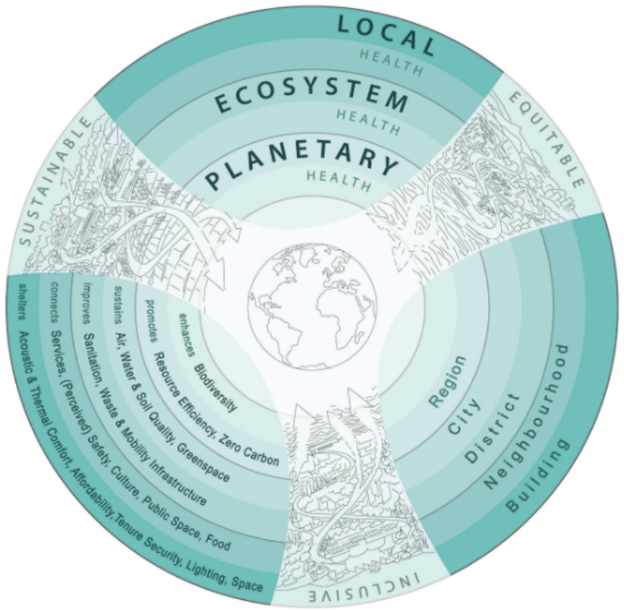


Figure 2.1. From top to bottom: Barton and Grant Health map (2005); Helen Pineo's THRIVES Framework: Towards Healthy uRbanism: InclusiVe Equitable Sustainable (2019).

2. Health and Well-being in the Climate Crisis

2.1. Defining Health and Well-being

Understanding how health and well-being are defined is critical to framing urban adaptation strategies that prioritize people, especially vulnerable groups, as core beneficiaries. In this research, health is not merely the absence of illness, but a dynamic state shaped by the environments in which people live, learn, and grow.

The World Health Organization (WHO) defines health as "***a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity"*** (WHO, 1948). This multidimensional view encompasses not only biological functioning but also emotional stability, cognitive capacity, and social connectedness, all of which are directly influenced by the surrounding environment.

Well-being, in this context, expands the focus to include subjective and developmental dimensions, such as vitality, comfort, happiness, and meaning. For children, well-being also contains opportunities for play, movement, exploration, and interaction – essential elements that support healthy development across life domains (OECD, 2019). In urban contexts, the environments where children spend their time—including homes, streets, and especially schoolyards—become crucial determinants of health and development.

Amid recent climate and environmental crises, more attention has been given to health, particularly in urban environments. In recent decades, the understanding of health has shifted from a narrow biomedical model to one that recognizes the complex interplay between individuals and their environments.
Early frameworks, such as Trevor Hancock's 1985 conceptual model of health, emphasized that health is shaped not only by individual behaviours and biomedical factors but also by broader social, economic, and environmental conditions. This systems-based thinking laid the groundwork for later visualizations, such as the Health Map by Barton and Grant (2006), which expanded on these ideas by developing a spatial model linking the natural and built environments, social networks, and community infrastructure as key determinants of population health.
The shift toward environmental determinants of health has also been highlighted in scholarly literature. Rydin et al. (2012) emphasize the complexity of urban systems and the need for planning approaches that integrate health into the design and governance of cities.
Building on this, the World Health Organization has introduced the concept of Urban Health, emphasizing how city design, infrastructure, and environmental quality directly influence well-being (WHO, 2016). Newer approaches, such as the THRIVE framework (2019), further connect human health to planetary boundaries, advocating for integrated solutions that respect both environmental limits and community needs (Pineo, 2019).

Growing scientific evidence confirms that environmental factors such as air quality, green space, mobility, and climate resilience play a critical role in health outcomes. The WHO's global assessment shows that over 23% of all deaths worldwide are attributable to modifiable environmental risks (Prüss-Ustün et al., 2016), reinforcing the need for environmental health strategies in urban design.

Health, therefore, is a complex, context-dependent concept influenced by diverse, interrelated factors across multiple scales and sectors.

>>> While a comprehensive review is beyond the scope of this thesis, the following sections focus on the most relevant interrelationships among health, climate change hazards, environmental stressors, and the built environment, seeking actionable strategies for architects and urban planners to improve quality of life and reduce climate- and environment-related health risks in cities.

2.2. Understanding Climate-Related Health Impacts Across Life Stages

Health outcomes resulting from climate change are influenced by a combination of **exposure to climate hazards** (e.g., extreme heat, flooding) and an **individual's vulnerability**, which includes biological, social, and economic factors (EEA, 2018). The accumulation of these factors determines resilience or susceptibility to adverse health impacts.

In urban settings, climate change affects physical, cognitive, emotional, and physiological health through both direct and indirect pathways (European Commission, 2020; WHO Europe, 2017; IPCC, 2022):

- **Direct effects** include increased mortality and morbidity from extreme heat, floods, and storms.
- **Indirect effects** include reduced physical activity due to thermal discomfort, psychological stress that can lead to or exacerbate mental health issues, disrupted sleep, and social isolation during extreme weather conditions.

Figure 2.2. Impacts of Climate Change Across the Life Stages. Vulnerability factors include: Biological factors and health status, sociopolitical factors, geographical factors, socio-economic factors, and intersecting inequalities. Source: Etzel et al., 2024.

Negative health effects are further intensified in cities where air pollution, heat, and noise levels are often higher. The following table summarizes age-specific health impacts of climate-related and environmental risks.

Table 2.2. Age-specific climate-related health impacts across developmental domains, with associated environmental risks. Adapted by author. Source: Etzel et al., 2024.

Age group	Physical domain	Cognitive domain	Psycological domain	Vitality
Pregnancy	Hypertensive disorders, low birth weight, and preterm birth; affects fetal brain and lung development (air pollution, extreme heat)	-	-	-
Infnts (0-2 yrs)	Impaired lung development; increased respiratory infections and asthma (air pollution; climate change (general))	Affected neurodevelopment (air pollution, extreme heat)	-	Impacts on strength and metabolic balance (food insecurity, poor nutrition, environmental stressors)
Children (2–12 yrs)	Respiratory diseases, asthma, and impaired organ development (air pollution, heat, climate-sensitive infections)	Reduced cognitive development (air pollution, heat)	Anxiety, depression, PTSD (natural disasters, climate crisis, eco-anxiety, solastalgia, extreme heat)	Nutritional deficiencies; reduced physical resilience (food insecurity, climate-induced crop failures)
Adolescents	-	Reduced cognitive capacity (air pollution, heat)	Anxiety, depression, PTSD, substance abuse (climate crisis, natural disasters, eco-anxiety, solastalgia)	-
Older adults	Heat-related illness; exacerbation of chronic conditions (extreme heat)	Accelerated cognitive decline (air pollution)	Depression, PTSD (climate crisis, extreme events, isolation (implied))	Reduced resilience; metabolic balance decline (poor living conditions, nutrition, lack of adaptation infrastructure)

A clearer pattern emerges when these impacts are grouped by developmental domains—physical, cognitive, psychological, and vitality—while explicitly linking each outcome to the main environmental risks reported in the source (e.g., air pollution, extreme heat, climate-sensitive infections, natural disasters, and food insecurity). This classification reveals not only which systems are affected but also how vulnerabilities shift across life stages.

Among all population groups, children are particularly vulnerable to both the direct and indirect health impacts of climate change (EEA, 2018). As shown in Table 2.2, vulnerable groups—especially children—face disproportionate risks due to the development of systems and behavioral patterns (e.g., outdoor play, physical sensitivity) and because key exposures often coincide in urban environments (notably air pollution and heat).

2.3. Air Pollution and Heat in Urban Environments: A Combined Health Threat

Air pollution poses significant health risks, particularly to children and adolescents, due to their developing bodies and behaviours that increase their exposure (EEA, 2023a; WHO Europe, 2021). Adhering to stricter air quality standards, as recommended by the WHO, is crucial to protect these vulnerable populations.

Children are particularly susceptible to air pollution due to several factors (EEA, 2023a; ISGlobal, 2021):

- **Developing Organs**: Children's lungs and other organs are still maturing, making them more vulnerable to pollutants.
- **Higher Breathing Rates:** Children breathe more air per kilogram of body weight than adults, resulting in a greater relative exposure.
- **Lower Physical Height:** Children inhale air closer to the ground, where traffic-related pollutants concentrate.
- **Behavioral Patterns:** Children spend more time outdoors and are more physically active, thereby increasing their exposure to outdoor air pollutants.

Emerging evidence also links ambient air pollution to long-term impacts on brain development and cognitive function. Chronic exposure to pollutants, especially fine particulate matter (PM5,10), nitrogen dioxide (NO2), and traffic-related emissions, has been associated with developmental delays, cognitive impairments, and possibly autism spectrum disorders (EEA, 2023a; ISGlobal, 2021).

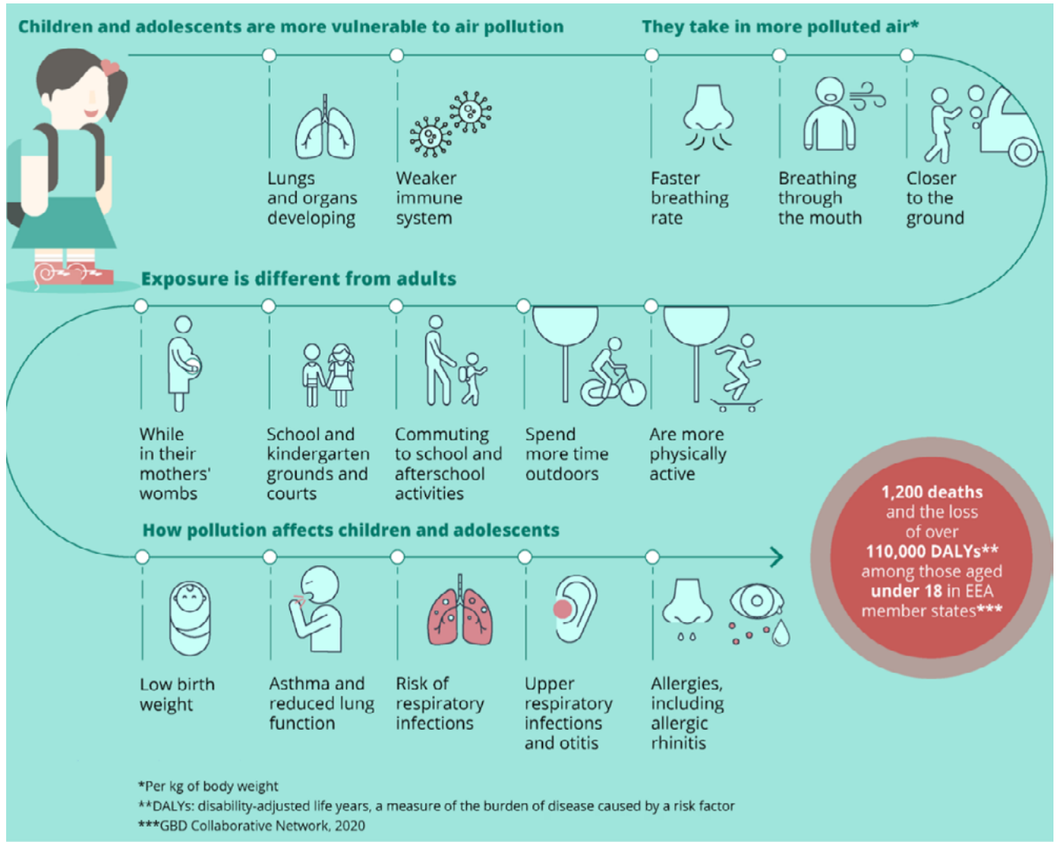


Figure 2.3. Children's vulnerability and exposure to air pollution. Source: EEA, 2023b.

TThe health impacts of air pollution are further exacerbated by rising urban temperatures, particularly during extreme heat. The relationship between climate change, air pollution, and health is both complex and synergistic. Evidence from the EEA and WHO indicates that urban heat amplifies the health risks posed by air pollution, particularly in cities, where children face cumulative exposure to multiple environmental stressors such as extreme heat, traffic emissions, and limited green space (EEA, 2023a; Nayebare et al., 2022; WHO Europe, 2017).

This is particularly true for pollutants such as particulate matter (PMK.K and PMKK), nitrogen dioxide (NOK), and ozone (OK), which become more concentrated or reactive under heat and sunlight (EEA, 2023c). The Urban Heat Island (UHI) effect, caused by impervious surfaces, a lack of vegetation, and built-up density, further exacerbates these conditions. Table 2.3. illustrates how key pollutants interact with extreme temperatures, and why their combined effects pose a disproportionate risk to child health (EEA, 2023b; ISGlobal, 2021).

Table 2.3. Air pollutants, child health effects, and links to urban heat. Source: EEA, 2023b.

Pollutant	Child health impact	Pollutant sources	Linked to UHI	How?
PM2.5 / PM10	Fine particles can penetrate deep into the lungs and even enter the bloodstream. Children's lungs are still developing, and they breathe faster than adults, increasing exposure. Associated with asthma, bronchitis, impaired lung function, and cognitive effects.	Vehicle exhaust, industrial emissions, domestic heating, construction sites, and natural sources like pollen and dust.	YES	Worsens during heatwaves: High temperatures increase atmospheric reactions, boosting PM formation. Heat traps particles, slows dispersion
NO_2	Asthma, impaired lung development Damages airways and reduces lung development and function. Strongly associated with childhood asthma onset and hospital admissions	Mainly from vehicle emissions and heating systems.	YES	Linked to urban heat: Heat can increase emissions from traffic and lower dispersion, concentrating NOK in street canyons. Emissions rise with heat, and dispersion slows
O_2	Asthma, lung damage, reduced immunity Triggers asthma attacks, reduces lung function, causes coughing, and throat irritation. Long-term exposure is linked to developmental issues and reduced immunity.	Not directly emitted; forms in sunlight from VOCs and NOx—more sunlight = more ozone.	YES Strongly	Strongly heat-related: Ozone formation is driven by sunlight and temperature; levels spike during hot, sunny days. Forms in high sun & temperature conditions

In unshaded, paved public spaces, especially in dense urban districts, exposure to both pollutants and elevated temperatures can be simultaneous and severe. The intersection of climate change and air pollution calls for both mitigation and adaptation strategies, particularly in child-sensitive environments, to reduce exposure to air pollution and heat stress. Urban design and planning strategies such as increasing vegetation and tree cover, creating shaded cooling zones, using permeable and reflective materials, and limiting vehicular traffic near schools, that mitigate both air pollution and heat exposure, are recommended by both EEA and WHO to reduce environmental health risks for children (EEA, 2023b; WHO Europe, 2017; ISGlobal, 2023).

Integrating these measures into public spaces and neighbourhood design can significantly reduce both exposure to air pollution and heat-related health risks, contributing to more climate-resilient, child-friendly urban environments.

2.4. Other Environmental Challenges and Urban Design Deficiencies

In addition to air pollution and urban heat, a broader range of environmental hazards significantly affects public health in urban areas. These include noise pollution, water and soil contamination, and loss of biotopes. Among these, noise pollution and biotope loss stand out for their pervasive and cumulative effects on physiological, cognitive, and emotional health (EEA, 2019; WHO, 2016). At the same time, many urban contexts face physical and spatial constraints that limit health-promoting behaviours. Poor access to green space, unsafe or fragmented pedestrian routes, and a lack of infrastructure for active mobility serve as barriers to physical activity, outdoor play, and contact with nature, all of which are critical for children's development and well-being (WHO, 2023).

Noise Pollution

Chronic exposure to environmental noise, particularly from traffic, construction, and densely populated urban areas, is a persistent issue in cities. It has been associated with cardiovascular strain, increased stress hormone levels, sleep disturbance, and impaired cognitive function. For children, the effects are particularly concerning: evidence links prolonged exposure to noise to reduced reading comprehension, memory deficits, difficulties in attention regulation, and lower academic performance (Stansfeld & Matheson, 2003; EEA, 2019).

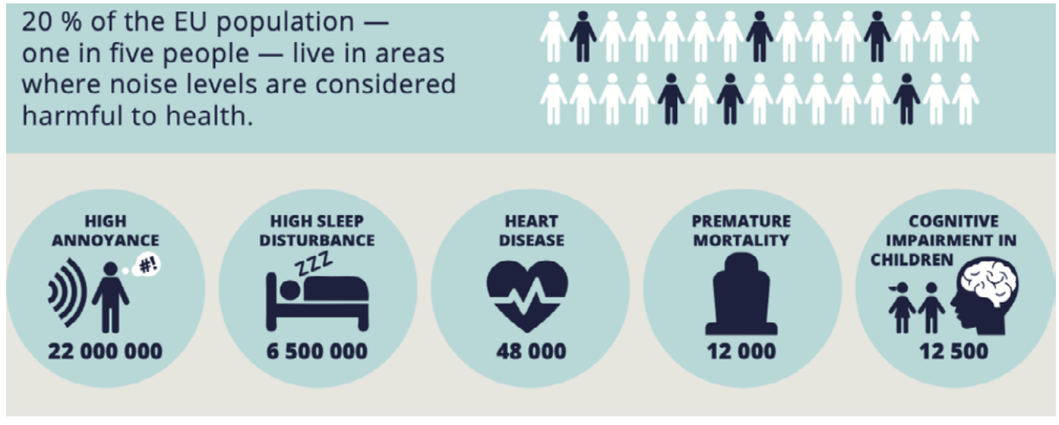


Figure 2.4.a. Noise pollution exposure and impacts in Europe. Source: EEA, 2019.

Biotope Loss and Reduced Access to Nature

Urban development often leads to the fragmentation and loss of natural habitats, reducing not only ecological biodiversity but also access to nature-rich environments that support health and development. Limited access to natural environments can lead to higher rates of anxiety and depression, lower levels of physical activity and outdoor play, and impaired attention regulation and reduced creativity (Gascon et al., 2015; WHO, 2016). Furthermore, the shrinking of biotopes (diverse natural spaces such as woodlands, wetlands, and meadows) limits children's exposure to microbial diversity, sensory stimulation, and opportunities for unstructured exploration (EEA, 2019).

Figure 2.4.b. The Health Benefits of Natural Spaces. Source: EEA 2019.

Reduced Physical Activity and Active Mobility
Limited opportunities for movement in urban areas due to a lack of safe sidewalks, poor street connectivity, or traffic-dominated environments further compound the impacts of biotope loss. These barriers contribute directly to sedentary lifestyles and rising childhood obesity, reduced motor skill development and metabolic imbalance, and increased psychological stress and social isolation (Sallis et al., 2016; WHO, 2023).

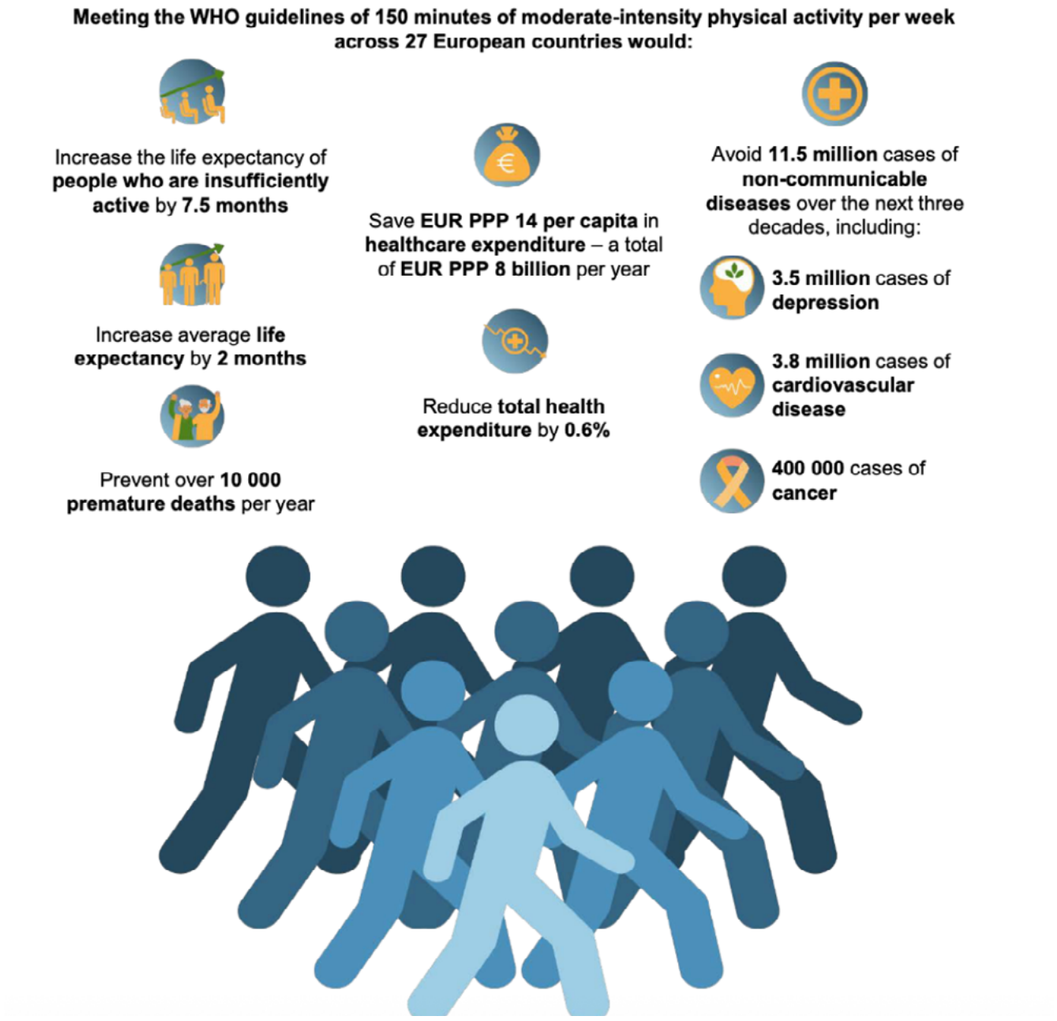


Figure 2.4.c The population health and economic benefits of physical activity. Source: WHO Regional Office for Europe, 2023.

Cumulative and synergistic health impacts of multiple stressors
In urban areas, people are continuously exposed to multiple environmental stressors, which often act simultaneously and, in some cases, synergistically, increasing health risks. This is particularly evident in the interaction between air pollution and high temperatures, which significantly increases morbidity and mortality rates (EEA, 2019). Vulnerable groups, including children, pregnant women, the elderly, and those living in poverty or with pre-existing conditions, bear a disproportionate burden of these risks. In European cities, a high percentage of children are exposed to environmental conditions that exceed health-based guidelines, with air pollution identified as the leading contributor to the estimated 211,000 disability-adjusted life years lost annually across EU Member States(EEA, 2019).

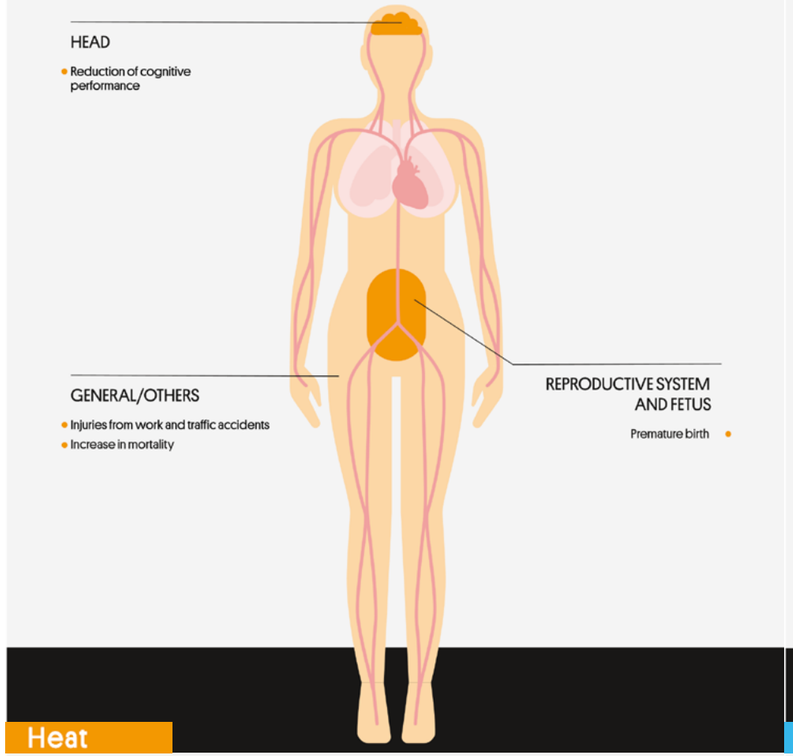
These findings underscore the need for early, spatially informed assessments that integrate environmental and social data to identify high-risk areas and guide equitable urban health interventions. Addressing these challenges requires an integrated approach to planning, one that prioritizes equitable access to non-polluted, quiet, biodiverse, and walkable environments (WHO, 2016; WHO, 2023).

Table 2.4. Overview of Key Urban Environmental and Climate Stressors and Their Health Impacts

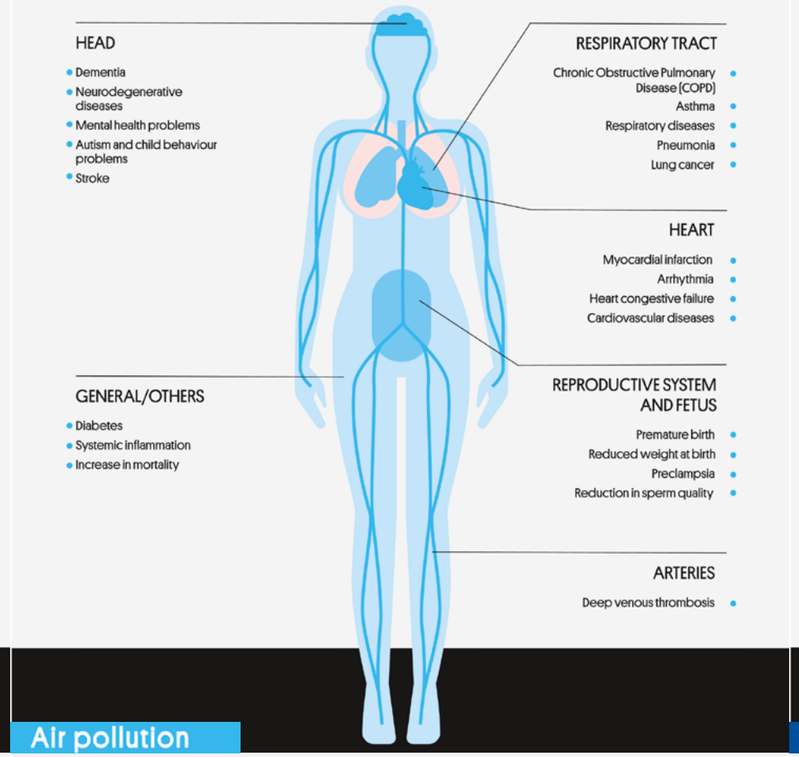
Stressor	Stressor Tyoe	Health Impacts	Affected Domains	Vulnerable Groups
Urban heat	Climate-related	Heat stress; dehydration; increased mortality	Physical; psychological	Children, elderly, outdoor workers
Air pollution	Environmental	Asthma; respiratory illness; cognitive impairment; cancer	Physical; cognitive	Children, elderly, pregnant women, people with pre-existing conditions
Noise pollution	Environmental	Sleep disturbance; stress; reduced attention; learning delays	Cognitive; psychological	Children, low-income and high-density urban communities
Biotope loss	Environmental	Obesity; anxiety; reduced immune regulation; attention issues	Physical; psychological; cognitive	Children, low-income families, urban populations with limited access to green space
Reduced Physical Activity	Urban design-related	Obesity; cardiovascular disease; metabolic disorders; low vitality	Physical; psychological	Children, adolescents, adults, elderly

Next page: Figure 2.4.d. Overview of the health effects of key urban environmental stressors.
Infographic set illustrating the systemic impacts of five major urban stressors: (from top left to right) heat, air pollution, noise pollution, limited access to natural spaces, and lack of physical activity. The diagrams highlight how each stressor affects different body systems—including respiratory, cardiovascular, cognitive, reproductive, and general health—and emphasize the cumulative burden these stressors place on vulnerable populations. Source: ISGlobal (2023), "Ciudades que queremos" campaign. Retrieved from https://www.isglobal.org/en/ciudadesquequeremos#contaminacion

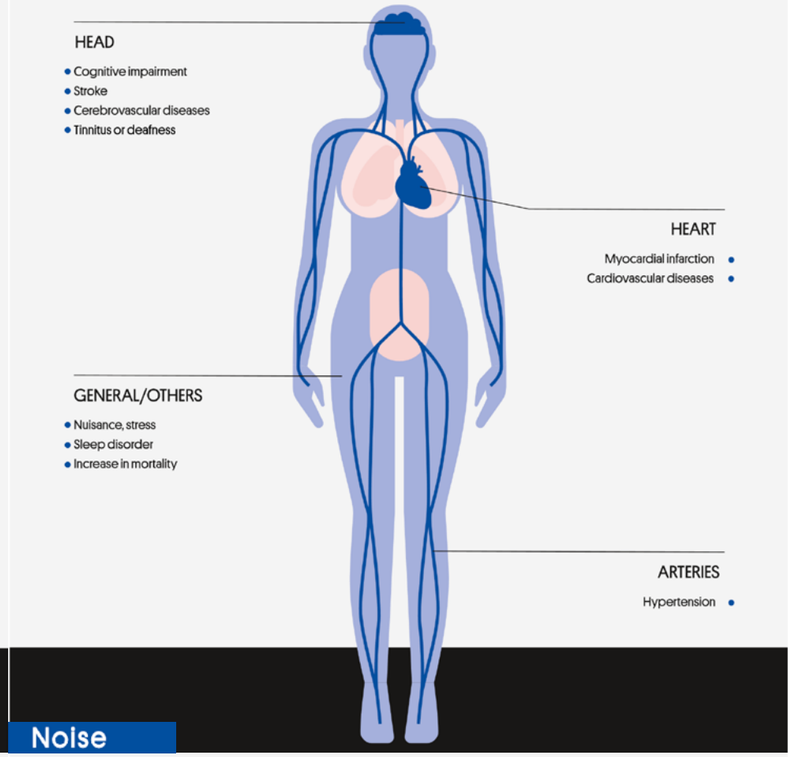
Heat



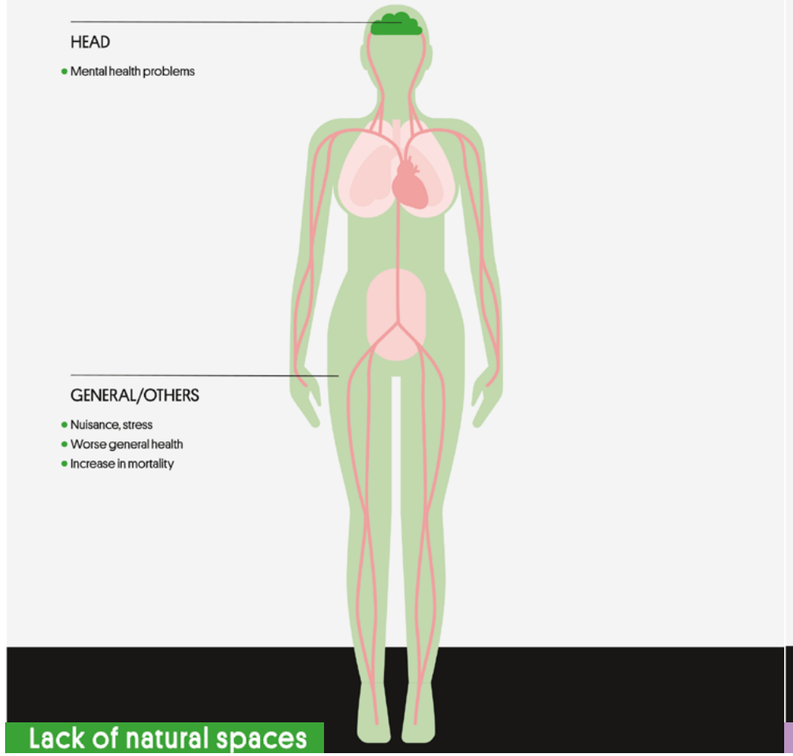
Air pollution



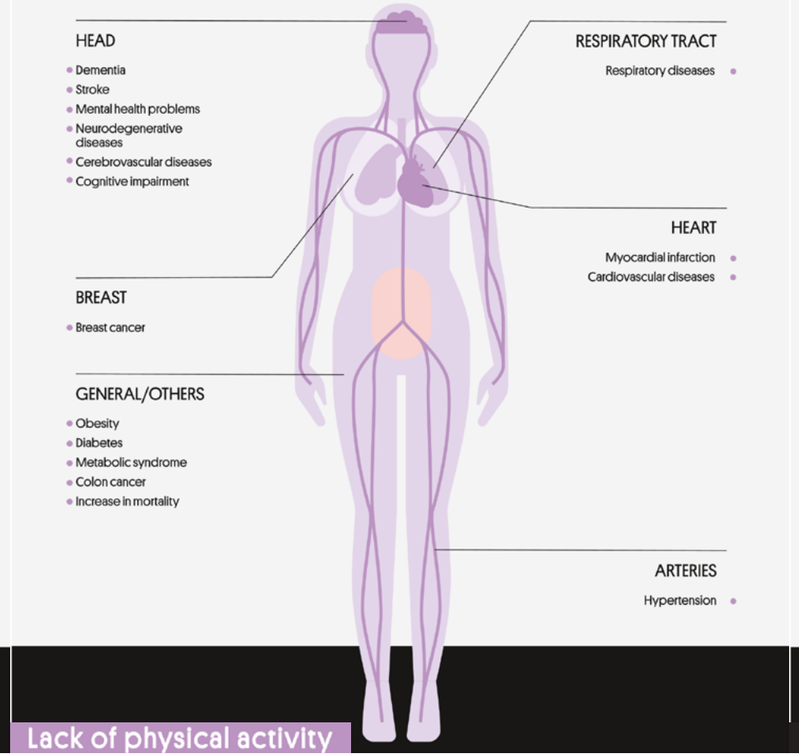
Noise



Lack of natural spaces



Lack of physical activity



All

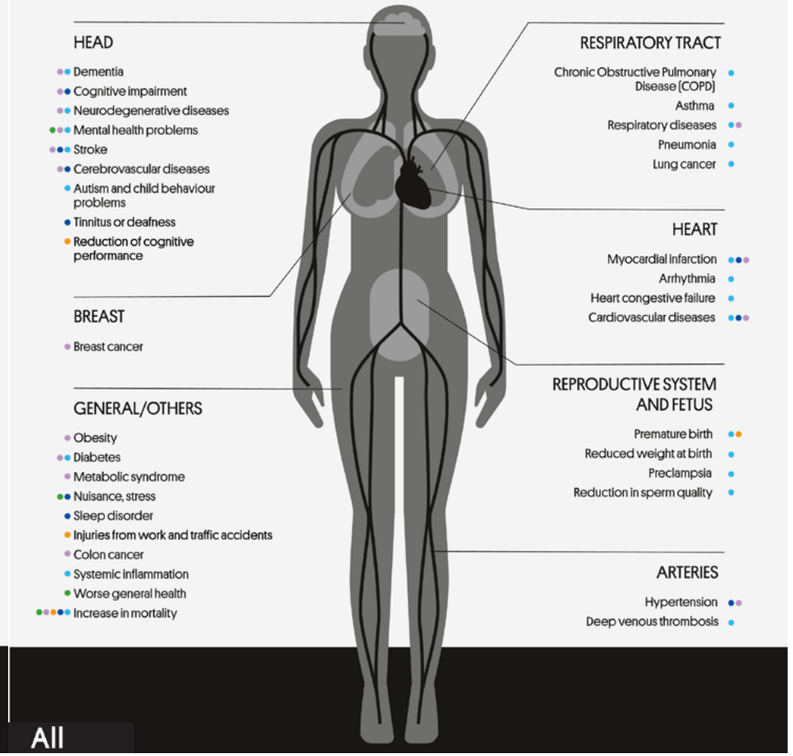


Figure 3.1. Coutryard of Liceo Scientifico Guido Castelnuovo in Florence, Italy.

3. Schoolyard as a Strategic Space for Change

3.1. Why Schoolyards Matter in Climate and Health Strategies

In line with the Ottawa Charter for Health Promotion (WHO, 1986), this thesis adopts a place-based approach:

"Health is created in the settings of everyday life – where people live, learn, work, love, and play."

In dense urban environments, where public space is increasingly scarce, schoolyards represent a rare and underutilized assets, one of the few universally accessed, publicly governed, and spatially embedded spaces that intersect daily with children's lives (Dyment & Bell, 2008).

Schoolyards are often one of the largest open spaces within neighbourhoods, embedded in community infrastructure and connected to both educational and municipal systems. Often, they are poorly addressed in policies on climate adaptation, public health, or urban development (Kelz, Evans, & Röderer, 2015). Most remain paved, shaded only by surrounding buildings, and stripped of ecological, social, and developmental richness. Their design reflects outdated priorities: supervision over stimulation, efficiency over equity, containment over creativity.

At the same time, children are a population group facing compounding vulnerabilities. Physiologically, they are more susceptible to heat and pollution due to their developing organs and metabolism (Landrigan et al., 2018; WHO, 2017). Developmentally, their growing systems are highly sensitive to environmental stimuli, making everyday exposures more impactful. Behaviorally, they are more exposed due to their play patterns and higher levels of outdoor activity (Ginsburg, 2007).

Moreover, today's children will be tomorrow's adults; their current environmental exposures will shape their long-term health trajectories and resilience capacities (WHO, 2017). Thus, reimagining schoolyards is not merely a spatial or pedagogical issue, it is a matter of intergenerational health, equity and climate justice.

By situating the schoolyard at the intersection of urban planning, health promotion, and climate adaptation, this research proposes a paradigm shift: from overlooked asphalt lots to multifunctional, inclusive, and regenerative spaces for both children and communities.

3.2. From Health Risk to Design Opportunity

In addition to children's particular vulnerability to urban stressors, their interactions with the urban environment are influenced by age-specific needs, sensitivities, and behaviours. This makes child development an essential framework for understanding and addressing environmental risks.

To address the environmental risks that children face, this thesis explores how everyday school-related micro-urban environments can mitigate these stressors, promote health, and support developmental needs. By applying the IPCC climate risk framework (hazard, exposure, vulnerability, adaptive capacity) to school-related environments, this analysis not only unravels the risks children face but also highlights the potential for transformation. The spatial strategies need to be evaluated not just for their technical performance but also for their ability to support holistic child health and well-being.

Furthermore, according to the IPCC 6th AR and several UN agencies (e.g., UNICEF and UNDRR), given the amount of time that children spend in school settings, adapting educational infrastructure and programmes to climate change is highly important. Transforming these spaces not only provides multiple benefits in terms of climate resilience, resource use, and improving overall health and wellbeing, but has the potential to raise awareness among students and the wider community, raising knowledge on climate adaptation (IPCC 6th AR, 2023).

By implementing integrated design solutions, such as permeable surfaces, trees, shade structures, and active zones, schoolyards can be transformed into multifunctional spaces that address both environmental and health challenges. Green schoolyards can provide cooling refuges during heat events, act as rainwater buffers during storms, and foster cognitive restoration through biophilic elements. Additionally, they can support physical activity by creating movement-friendly landscapes that encourage metabolic activation.

To achieve this, a new approach is needed that integrates climate adaptation, supports childhood development, and advances environmental justice, all within the neighbourhood and environments where children live, learn, and play.

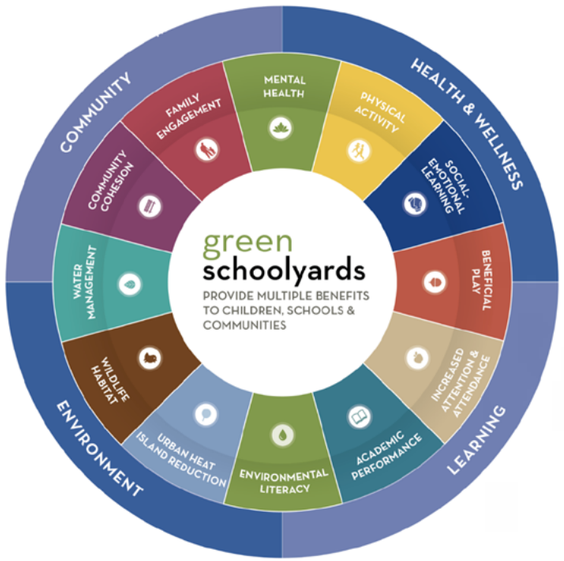


Figure 3.2. Transforming schoolyards into climate-resilient spaces provides multiple benefits to its students, the surrounding community, and the city itself. Source: Children & Nature Network, 2017.

3.3. Research Aim & Questions

The research aims to address the urgent need to align climate adaptation strategies with child health promotion in the context of increasingly urbanized, unequal, and environmentally stressed societies. The transformation of school-related spaces into climate-resilient, health-promoting environments requires evidence-based strategies and practical tools. To support this effort, this thesis examines how environmental design can mitigate risks, address developmental needs, and inform future policies and planning frameworks.

The main goal of the research is to develop a scientifically grounded, design-oriented framework and toolkit that supports the design of school-related environments as climate-resilient, health-promoting, and developmentally supportive.

Research Questions

To ensure a coherent development of the research, the investigation is structured around three core Research Questions (RQs). Each RQ reflects a distinct phase of the research process: RQ1 explores the conceptual foundations and the risk context; RQ2 examines existing practices and extracts empirical insights; and RQ3 informs the development of a practical design framework. This structure enables a logical progression: from understanding needs and risks, to learning from practice, to proposing actionable solutions.

By addressing these questions, the research aims to bridge gaps between climate science, urban health, and child-centered design, and contribute both to academic knowledge and practical solutions.

RQ1 **What are the key health, well-being, and developmental needs of children in schoolyards, and how are these shaped by climate and environmental risks?**

- *What does health, well-being, and child development entail in the context of schoolyard environments?*
- *Which climate and environmental risks most affect children's health and development in schoolyards?*
- *How do exposure, vulnerability, and adaptive capacity vary by age, context, and schoolyard characteristics?*
- *Which design elements mitigate or exacerbate specific risks – and how can they be aligned with health and developmental outcomes?*

RQ2 **What can current schoolyard transformation practices teach us about designing for health and climate resilience?**

- *What trends, priorities, and methodologies characterize recent schoolyard transformation projects?*
- *What are the main enablers and barriers in implementing health- and climate-oriented interventions?*
- *Which concrete strategies and solutions can inform future, context-sensitive applications?*

RQ3 **How can a design framework support the transformation of schoolyards into climate-resilient, health-promoting environments?**

- *What tools, methods, and guidelines are needed to support municipalities, designers, and school communities?*
- *How can the framework be adapted to varying needs, scales, and levels of transformation – from strategic planning to participatory design?*

Closing remarks

Part I of the thesis has framed the urgent need to integrate climate adaptation and health promotion in urban settings, with a specific focus on children as a vulnerable group and schoolyards and school-related environments as strategic spaces for intervention. By applying a systems lens to the overlapping domains of climate risk, environmental stressors, and childhood development, the research positioned schoolyards not only as sites of exposure and vulnerability but as underutilized assets with the potential to become inclusive, regenerative public spaces.

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PART II -

School-related environments as drivers of change

Building upon the critical challenges highlighted in Part I, this section focuses on schoolyards and school-related environments as strategic urban spaces where resilient and healthy transformations can be tested and scaled.

Schoolyards, as neighborhood-scale public spaces used daily by children and educational communities, represent a unique opportunity to integrate resilient design, health education, and the promotion of physical activity. This chapter explores the strategic role of schoolyards and school-related spaces as the central case study of this research.

Figure 4. Space to Grow projetc, Chicago, USA.

4. Schoolyards as urban assets for resilience and well-being

4.1. Introduction

As discussed in Chapter 3.1, schoolyards represent a unique and largely untapped public resource. Despite their daily use, schoolyards are often treated as private or secondary spaces, fenced off, inaccessible outside school hours, or made available only to specific groups such as cultural and sports associations. Overheated, impermeable, and socially exclusive environments, schoolyards fall short of supporting children's development or broader community resilience (Dyment & Bell, 2008; Kelz et al.).

Present in almost every neighbourhood and accessed by millions of children each day, schoolyards offer an unparalleled opportunity to act as micro-urban climate regulators, health-supporting environments, and inclusive learning and play spaces (Nieuwenhuijsen, 2021).

The transformation of schoolyards aligns with multiple international policy frameworks. The WHO's Health in All Policies approach and the European Green Deal both emphasize the need for place-based, cross-sectoral interventions that prioritize the health and development of future generations. In this context, rethinking schoolyards as urban commons: shared, multifunctional, and accessible spaces that makes a direct contribution to climate adaptation, health, and social inclusion.
A growing body of evidence highlights the potential of green and inclusive schoolyards to simultaneously deliver environmental, health, developmental, and social equity benefits (Frumkin et al., 2017; Sanz-Mas et al., 2025; Gallez et al., 2024). These include:

- **Environmental benefits** (e.g., reduced urban heat island effect, improved stormwater management, enhanced biodiversity),
- **Health benefits** (e.g., better thermal comfort, air quality, mental well-being),
- **Developmental and educational benefits** (e.g., increased physical activity, sensory and cognitive stimulation, nature-based learning),
- **Social and spatial equity benefits** (e.g, access to quality public space, intergenerational and gender-inclusive design).

The challenge, however, lies in unlocking their potential through integrated design approaches that are grounded in scientific evidence, responsive to local conditions, and inclusive of children's needs and rights.

4.2. Summary of Literature: Gaps & Opportunities

To address the challenges outlined in Part I, an extensive literature review was conducted on recent scientific and grey literature on schoolyard transformation as a climate-adaptive, health-promoting, and inclusive environment. The aim was to identify emerging opportunities, barriers, and design strategies that support systemic change.

The review followed a systematic approach, integrating studies from architecture, public health, education, environmental psychology, urban planning, and sustainability science. Key search terms included: green schoolyards, schoolyard transformation, nature-based solutions in schools, schoolyard health impacts, outdoor learning environments, child development and play environments, climate adaptation in schools, and outdoor comfort in schoolyards. The review covered academic repositories, including Scopus, Web of Science, and PubMed, as well as grey literature databases such as Google Scholar and EU and WHO portals.

The final dataset comprised over 100 peer-reviewed articles and reports published between 2000 and 2024, with a focus on interdisciplinary works that addressed both environmental and developmental outcomes in schoolyard design. Key inclusion criteria were: 1) focus on outdoor environments across all educational level settings, 2) empirical or practice-based evidence, 3) clear connection to climate, health, NbS, or physical activity, and 4) relevance to design or policy.

The findings are structured into three core sections: (1) recurring risks and design deficits, (2) transformative opportunities and enablers, and (3) cross cutting themes emerged.

4.2.1. Recurring Risks & Deficits in Schoolyard Environments

Unfortunately, the current condition of most schoolyards falls short of supporting these systemic goals. A growing body of research highlights a range of physical, environmental, and socio-spatial deficits that limit schoolyards' functionality and inclusivity:

- **Thermal discomfort and solar exposure:** Asphalt-dominated surfaces with little or no tree canopy contribute to excessive heat gain, increasing thermal stress during warmer months (Sebos et al., 2023; WHO, 2016).
- **Air and noise pollution:** Schools located near major roads are exposed to elevated levels of PM2.5 and chronic traffic noise, both of which are linked to reduced attention, cognitive function, and respiratory health (Flax et al., 2023; Gacon et al., 2015).
- **Lack of biodiversity and sensory richness:** Many schoolyards rely on low-diversity vegetation (e.g., monoculture lawns) and hard surfaces, which limits their ecological value and multi-sensory engagement (Giezen & Pellerey, 2021; WHO, 2016).
- **Exclusion across age and gender lines**: Uniform, sports-centric design tends to marginalize certain users – particularly girls, older students, or neurodivergent children – who may not find the space responsive to their needs (Andersen et al., 2022).
- **Barriers to replication and scaling:** Even successful pilot projects face institutional and governance-related obstacles to widespread adoption, including unclear maintenance responsibilities, funding, and insufficient intersectoral collaboration (Giezen & Pellerey, 2021).
- **Inequitable spatial distribution:** Greener and more innovative schoolyards tend to be concentrated in wealthier municipalities, reinforcing existing patterns of spatial inequality and environmental injustice (Gallez et al., 2024).

These challenges call for systemic and context-sensitive solutions that acknowledge both infrastructural and governance difficulties.

4.2.2. Opportunities & Levers for Change

Despite these limitations, the literature identifies several design and policy opportunities that can support more inclusive, climate-resilient, and health-promoting schoolyards:

- **Nature-based Solutions (NbS):** Integrating trees, green roofs, rain gardens, pollinator habitats, and edible gardens into schoolyard design delivers microclimatic benefits, promotes biodiversity, and enriches educational content (Sanz-Mas et al., 2025; Prüss-Ustün et al., 2016).
- **Co-design with children and educators:** Participatory design processes foster user ownership, reveal overlooked needs, and enhance long-term stewardship and functionality (Kanai & Fabio, 2022; Andersen et al., 2022).
- **Integrated play and sport elements:** Play trails, activity circuits, and multi-zoned yards promote motor development and active use across different age groups, reducing sedentary behavior and supporting physical education (Dyment & Bell, 2008; Andersen et al., 2022).
- **Neurodiverse and sensory-sensitive design:** Introducing quiet zones, textured surfaces, varied materials, and refuge areas accommodates diverse cognitive and emotional profiles, including those of children with sensory processing differences (Gallez et al., 2024; Frumkin et al., 2017).
- **Monitoring and adaptive management tools:** Technological and participatory tools such as thermal imaging, air quality sensors, and climate audits support evidence-based design, risk monitoring, and responsive interventions (Sebos et al., 2023).

Taken together, these strategies point toward a new model of schoolyard transformation: one that is data-informed, participatory, ecologically grounded, and inclusive by design.

Table 4.2.2. Summary table: Gaps vs. Opportunities

Topic	Recurring Gaps/Risks	Emerging Opportunities
Thermal Comfort	Asphalt-dominant yards, lack of shade, radiant heat exposure	Tree canopy, green roofs, permeable surfaces, thermal comfort audits
Air & Noise Pollution	Proximity to traffic, poor air quality, chronic noise	Vegetative buffers, spatial orientation, air/noise monitoring systems
Biodiversity & Sensory Diversity	Lawns with low ecological value, hard materials	Pollinator habitats, edible gardens, varied materials and microhabitats
Equity & Inclusion	Gender- and age-biased design; underuse by neurodiverse or older children	Inclusive play elements, co-design processes, sensory and social affordances
Physical Activity	Sedentary design, lack of structured movement pathways	Play trails, loop paths, open-ended topographies, affordances for all abilities
Pedagogical Use	Underuse for teaching; indoor-centric curricula	Outdoor classrooms, green curriculum integration, flexible learning zones
Spatial Injustice	Greener yards concentrated in affluent areas	Equity-based public investment, common-good framing, accessibility policies
Scaling & Governance	Fragmented ownership, unclear maintenance, regulatory inertia	Whole-school approaches, municipal-school partnerships, strategic frameworks

4.3. Cross-Cutting Themes Emerging from the Literature Review

In addition to the distinct functions of climate resilience, health promotion, physical activity, and child development, several cross-cutting themes consistently emerge across the literature. These themes reflect the systemic nature of schoolyard transformation, where design decisions ripple outward to affect urban metabolism, educational outcomes, social dynamics, and ecological functioning. Recognizing and integrating these transversal dimensions is essential for developing comprehensive design frameworks and evaluation methodologies.

Equity & Inclusion
A recurring concern in the literature is the role of schoolyards in addressing health and environmental disparities. Children from marginalized, low-income, or racially minoritized communities often attend schools with poorer infrastructure, less vegetation, and higher exposure to environmental stressors such as noise and air pollution (Gallez et al., 2024). Transforming schoolyards in these areas is not only a matter of aesthetics or play, but a direct intervention in spatial justice. However, while many studies highlight the need for equitable design, only a few provide operational strategies or measurable indicators to assess whether interventions truly benefit the most vulnerable. Ensuring inclusive access, affordances for all abilities, and co-benefits for families and neighbors are emerging priorities (Floyd et al., 2020).

Systemic Thinking & Multifunctionality
The most impactful schoolyard interventions are those designed with multifunctionality in mind, delivering simultaneous environmental, educational, and social benefits. Instead of isolated technical fixes (e.g. a rain garden or a sports court), effective designs combine layers of function—such as a shaded learning area that also manages runoff, or a pollinator garden used for science classes and community events (Sanz-Mas et al., 2023). This systems thinking approach is essential to scale up impacts and avoid trade-offs between goals. Moreover, integrating schoolyards into broader urban ecological networks—linking green corridors, active mobility paths, and public space strategies is crucial for a wider and long-term impact.

Co-Design & Participation
Across the literature, participatory processes involving children, educators, and communities are cited as key to successful and sustainable schoolyard interventions. Participatory methods increase users' sense of ownership, improve the fit between design and real-world needs, and often result in more inclusive and creatively imagined spaces (Nasri et al., 2022). In particular, child-led design activities reveal insights into how children perceive and use space—insights that adult designers often overlook. Co-design is also a pathway for civic engagement, intergenerational exchange, and educational enrichment.

Evidence-Based Practice
There is growing interest in using quantitative and qualitative tools to assess both the process and outcomes of schoolyard transformations. Methods such as behavioral mapping, thermal comfort audits, air quality monitoring, and biodiversity indexing are increasingly employed to evaluate the effectiveness of design strategies (Fjørtoft & Sageie, 2009; Nasri et al., 2022). The integration of data allows for adaptive management, data-informed decision making, and the replication of proven approaches. Nevertheless, standardized indicators and open-access tools remain scarce, limiting comparability and knowledge transfer.

Temporal Flexibility & Scalability
A less visible but equally critical theme is the need for designs that evolve over time. Schoolyards are dynamic environments: user needs shift with age and pedagogy; climate conditions fluctuate seasonally and annually; and institutional priorities may change with new leadership or policy mandates. Designs must allow for modularity, phasing, and stewardship, ensuring long-term adaptability. At the same time, strategies should be designed with scalability and replication in mind, avoiding overly customized solutions that are difficult to apply in other contexts or at larger scales (Sanz-Mas et al., 2023).

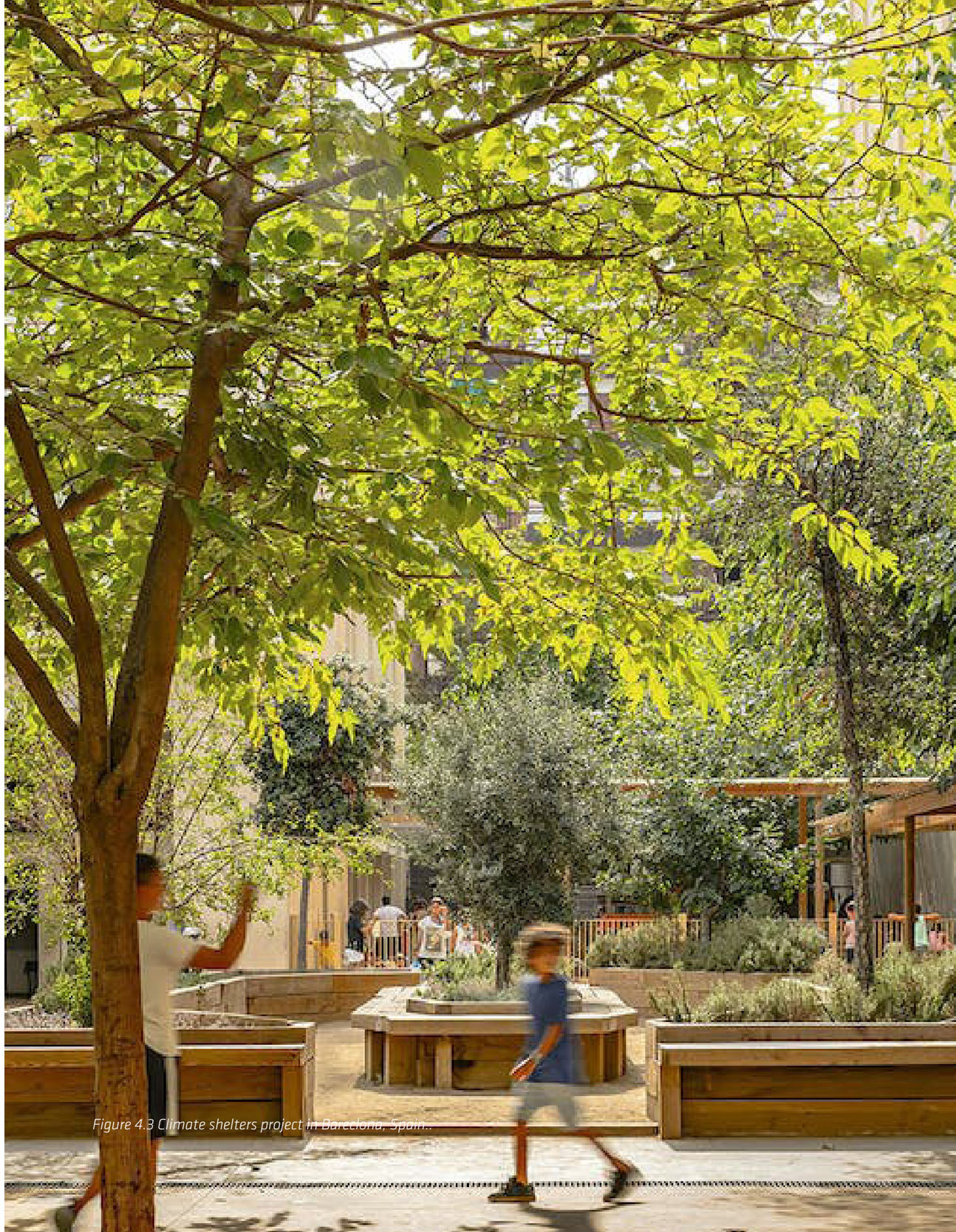


Figure 4.3 Climate shelters project in Barcelona, Spain..

4.4. Identified Opportunties & Gaps

4.4.1. The Multifunctional Role of Schoolyards

Historically conceived as mono-functional spaces reserved for recess and passive recreation, schoolyards are now increasingly framed as micro-infrastructures with the potential to deliver multiple co-benefits previously mentioned. Literature from environmental health, urban planning, education, and child development recognizes the multifunctionality of well-designed schoolyards that can act as:

- **Climate buffers**: Vegetated and shaded schoolyards mitigate urban heat through evapotranspiration and canopy coverage, improve stormwater retention, and support ecological diversity (Sanz-Mas et al., 2025; Sebos et al., 2023).
- **Health-promoting spaces:** Contact with nature in schoolyards improves mental health, reduces stress biomarkers such as cortisol, and encourages social interaction and physical activity (Floyd et al., 2020; Bratman et al., 2019; WHO, 2017).
- **Developmental and learning environments:** Outdoor environments have been linked to increased attention span, better executive function, and cognitive flexibility in children (Kuo et al., 2019; Sam & Kouhirostami, 2020).
- **Gender-responsive spaces:** Renovated schoolyards can offer diverse affordances, reduce gender-based activity disparities and promote more equitable access (Andersen et al., 2022).
- **Climate resilience hubs:** Green schoolyards are increasingly proposed as local adaptation nodes often called 'climate shelters', providing hydration points, and cooling infrastructure during heatwaves and floods (Sebos et al., 2023; Flax et al., 2023).
- **Public micro-infrastructure:** Especially in low-income or underserved areas, schoolyards act as de facto public spaces – providing safe, accessible, and inclusive areas for play, rest, and social connection (Giezen & Pellerey, 2021; Landrigan et al., 2018).

Together, these findings support the re-framing of schoolyards as multi-benefit urban commons, everyday spaces with the potential to support equity, resilience, development, and sustainability simultaneously.

4.4.2. Research gaps

Despite the growing body of research on schoolyard transformations, several important gaps persist in both academic literature and practical implementation. These gaps limit the ability of current approaches to fully deliver on the promise of healthier, more inclusive, and climate-resilient school environments.

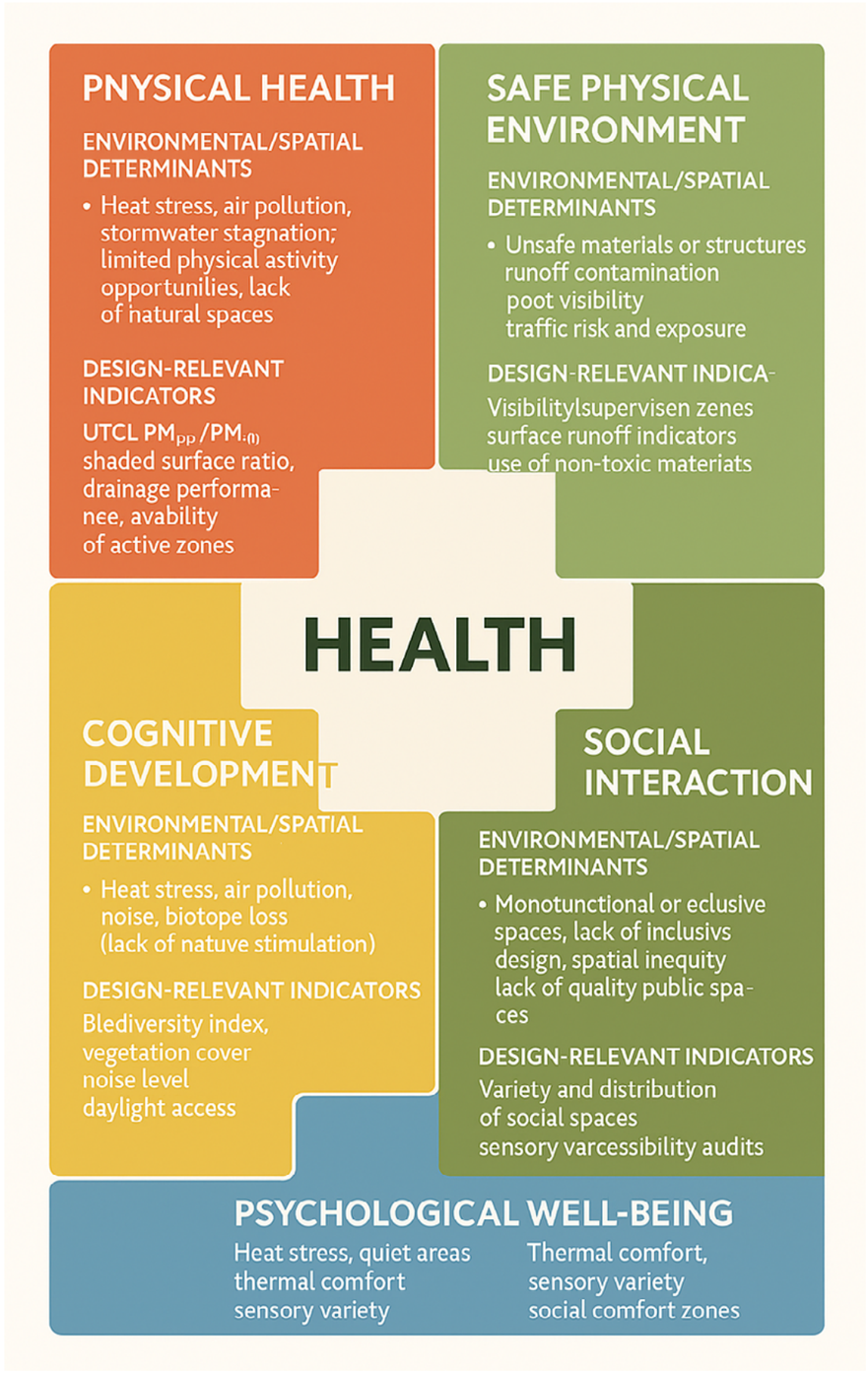
One of the most significant shortcomings is the **lack of long-term health and developmental evaluations**. While many studies report increases in physical activity after interventions, few go beyond short-term metrics. Broader outcomes, such as improvements in cognitive development, stress regulation, or emotional well-being, are rarely tracked over time (Bratman et al., 2019). As a result, there is still little evidence on the impact of green and adaptive schoolyards on children's health trajectories beyond immediate physical behavior.

Another limitation is the **scarce application of climate risk frameworks**. Although awareness of the climate challenge is growing, very few schoolyard projects systematically assess exposure to heat, flooding, or air pollution using established tools such as the IPCC's hazard–vulnerability–exposure model. Climate risks are often addressed with general greening strategies, but without clear prioritization or diagnostics (Sebos et al., 2023). This limits the effectiveness of interventions, especially for schools located in areas most affected by environmental stressors.

Equity and inclusion are frequently discussed, yet there remains a lack of operational tools and indicators to assess whether schoolyards are truly accessible and beneficial for all children. Many studies call for equitable investment and inclusive design, but few provide measurable criteria for evaluating gender sensitivity, accessibility for children with disabilities, or the distribution of green schoolyards across different neighborhoods (Gallez et al., 2024). Without such indicators, it is difficult to identify disparities or ensure accountability in schoolyard renewal strategies.

Finally, current practices often suffer from **fragmentation across sectors**. Schoolyard projects are typically shaped by a narrow set of actors, such as educators or architects, without meaningful input from health professionals, climate experts, or urban planners. This siloed approach leads to missed opportunities for synergy and hinders the development of integrated strategies that can serve multiple goals simultaneously (Floyd et al., 2020; Giezen & Pellerey, 2021). As a result, promising solutions often remain isolated pilot projects, rather than scalable and replicable models.

Together, these gaps highlight the need for a more integrated, evidence-based, and equity-oriented approach that combines climate diagnostics, health indicators, participatory design, and spatial analysis to inform the future of schoolyard transformation.



Each health domain is influenced by concrete environmental and spatial conditions, many of which are present in everyday urban environments. Figure 5.1. how they can be evaluated through specific, measurable indicators.

5. From Concept to Practice: What Makes School-Related Environments Resilient, Healthy, and Active?

5.1. Health and Well-being as the Foundation for the Design

According to the World Health Organization, health is defined as "***a state of complete physical, mental, and social well-being.***" The Ottawa Charter for Health Promotion (WHO, 1986) further reinforces that definition, stating that health is created and lived "***where people live, learn, work, play, and love.***"

As the climate crisis intensifies and cities face growing health inequalities, **schools and school-related micro-urban spaces emerge as critical settings for building long-term resilience.** For children, health is not only shaped by biological factors but also by their **daily experiences in the environment**, where they move, play, learn, interact, and grow. In this context, **school-related environments can be viewed as strategic public health infrastructure,** particularly due to their role in shaping children's exposure to environmental stressors and resources (WHO, 2017; Bratman et al., 2019; Chawla, 2015).

Based on this, the research adopts a place-based understanding of health and positions school-related environments as spaces where environmental conditions (seen both as risk drivers and opportunities) are concentrated, leading to the design question:

>>> Which spatial conditions can we modify to reduce children's exposure and vulnerability to climate hazards and environmental stressors, while supporting healthy child development?

To answer this question, the research explored interdisciplinary literature in public health, child development, and environmental psychology (UNICEF & WHO, 2020; Dodge et al., 2012; Halfon et al., 2014), to create a shared definition of **child health and well-being**, which follows:

"***Child health and well-being refer to a holistic state of physical, mental, emotional, and social functioning that enables children to grow, learn, play, and thrive in a safe and supportive environment.***"

This definition is operationalized through five interrelated health domains:

- **Physical health**: Growth, immunity, absence of illness, access to clean air and water, healthy movement, and adequate nutrition (WHO, 2020; Floyd et al., 2020; Singh et al., 2012).
- **Cognitive development:** Learning capacity, memory, concentration, and knowledge acquisition (Singh et al., 2012; OECD, 2020).
- **Psychological well-being:** Feeling safe, emotionally supported, confident, and free from excessive stressors (Bratman et al., 2019; Dodge et al., 2012).
- **Social well-being:** The ability to connect, cooperate, and communicate, developed through inclusive, peer-supportive spaces (UNICEF, 2020; Jennings & Bamkole, 2019).
- **Environmental health and safety:** Protection from harmful exposures such as air pollution, UV radiation, unsafe surfaces, poor visibility, and climate-related risks (WHO, 2017; Kabisch et al., 2016; Abhijith et al., 2017; van den Bosch & Sang, 2017).

5.1.1. Framing Health and Developmental Risk through an Adapted IPCC Model

To assess how environmental and spatial conditions affect children's health and development, the research proposes an adapted version of the Intergovernmental Panel on Climate Change (IPCC) risk framework, as shown in Table 5.1.1. In the original AR6 model, risk is defined as the interaction of hazard, exposure, and vulnerability, with "response" playing a mediating role.

Table 4.1.1. Adapted IPCC Risk Framework: Risk results from the interaction of hazard, exposure, and vulnerability, leading to health, well-being, and developmental impacts in children.

Component	In Climate Risk Framework (IPCC)	Adapted for child Health
Hazard	Climate event (e.g., heatwave, flood)	Environmental or climate stressor (e.g., heat, poor air quality, noise, flooding, pollution, UV)
Exposure	People/systems in harm's way	Children in outdoor spaces (e.g., schoolyards, streets, homes)
Vulnerability	Lack of protection, sensitivity to impact	Children's higher sensitivity due to physiology, developmental stage, limited autonomy, and social dependency
Response (AR6 addition)	Measures to reduce or address risk	Design, planning, or policy solutions (e.g., shading, water access, quiet zones, cooling infrastructure) that can reduce or worsen health outcomes

In this research, the model is reframed to examine how chronic or acute environmental hazards (e.g., heat, pollution, biotope loss) interact with children's exposure (e.g., presence in schoolyards and urban spaces) and developmental vulnerability (e.g., physiological sensitivity, developmental, etc.) to produce specific health and developmental risks. In this context, design is interpreted as a form of response, a strategic intervention that can either mitigate or increase the risks. By aligning climate resilience and child development within this risk framework, the research builds a foundation for linking spatial analysis, design strategies, and child-centered evaluation tools. The figure 5.1.1. illustrates the adaptation of the IPCC Framework to the research.

In applying this adapted risk framework to school-related environments, **five design-relevant risk drivers** emerge as particularly influential in shaping child health and development:

1. Extreme temperatures (Urban Heat Island)
2. Extreme precipitations (Stormwater Run-off)
3. Biotope loss,
4. Physical (in)activity,
5. Spatial inequity.

Each of these represents a chronic or compounding driver of risk that interacts with children's developmental vulnerability and spatial exposure, often with cumulative effects. These risk drivers are not only factors to be reduced but also design challenges that, if addressed effectively, can transform schoolyards into health-promoting, developmentally supportive environments. To operationalize this logic, the research translates these core risk drivers into five thematic design lenses, analysed across three interrelated spatial scales.

Child development is treated as the primary lens in this five-lens set, serving as the interpretive lens through which exposure and vulnerability are read across ages and contexts.

Figure 5.1.1. Adapted IPCC Risk Framework showing the interaction between hazard, exposure, and vulnerability in shaping child health, well-being and developmental outcomes. Source: Adapted by the author from IPCC Sixth Assessment Report (2023).

The following sections, therefore, introduce five key lenses that shape the design of resilient, health-promoting, and developmentally supportive school environments: Child Development, Climate Resilience (heat and stormwater), Biotope Loss, Physical Activity, and Spatial Equity.

The following sections introduce **six key themes** that shape the design of resilient, health-promoting, and developmentally supportive school environments. Beginning with **child development as the guiding lens**, each subsequent section explores specific environmental or spatial risks, including urban heat and flooding, biotope loss, physical inactivity, and spatial inequity, highlighting their impacts on children and the implications for the design of school-related environments.

The themes are examined not only at the level of the schoolyard but across the broader system of spaces that children navigate daily, from surrounding neighborhoods to school premises and outdoor play areas, ensuring that design responses address risks across three interrelated spatial scales:

- the neighborhood level (macro),
- the school premises (meso),
- the schoolyard and micro-environments (micro).

Each thematic chapter follows a common structure:

- Introduction of the hazard and its relation to health,
- Esploration of methods and tools for its evaluation,
- Outlining the determinants that shape its manifestation inclusing respective indicators for analysis and evaluation,
- Presentation of existing design strategies and solutions,
- Closing remarks.

This structure allows for first gaining an understanding of the health implications of a particular risk driver, followed by the exploration of spatial factors and their determinants that lead to, or influence, the hazard's manifestation in the urban context. The list of indicators and strategies ensures the practicality of each chapter for analysis, design, and planning purposes.

5.1.2. Scope and focus of the study

While air and noise pollution are recognized as significant environmental stressors impacting children's development and health, particularly cognitive performance, respiratory health, and emotional regulation (EEA, 2019; EEA, 2022; WHO, 2011), they are not addressed as standalone themes in this framework.

This decision is based on two primary considerations. First, the framework prioritizes adaptation-oriented risks that can be directly addressed through spatial and design strategies within school-related environments. Second, both air and noise pollution are typically shaped by broader urban systems and traffic regulation, often requiring policy-level mitigation rather than site-level spatial adaptation.

Nonetheless, elements of air and noise risk management are indirectly addressed under themes such as biotope loss (e.g., vegetation buffers), spatial inequity (e.g., proximity to roads), and child development (e.g., need for restorative and quiet spaces).

Figure 5.2. Boston Schoolyard Initiative, Boston, USA.

5.2. Designing for Developmental Needs– Primary Design Lens

To ensure that design strategies are grounded in the specific needs, capacities, and experiences of children, child development is introduced as the primary cross-cutting lens through which environmental risks/hazards are understood and analyzed. **Child development is one of the key determinants of health** (WHO, 2021; UNICEF, 2020). Early experiences shape lifelong patterns of health and well-being through what the literature refers to as life-course health development (Halfon et al., 2014). Child development in detail refers to the **biological, psychological, and emotional changes** that occur in human beings between birth and the end of adolescence. It is a multidimensional process involving the acquisition of skills across several interconnected domains.

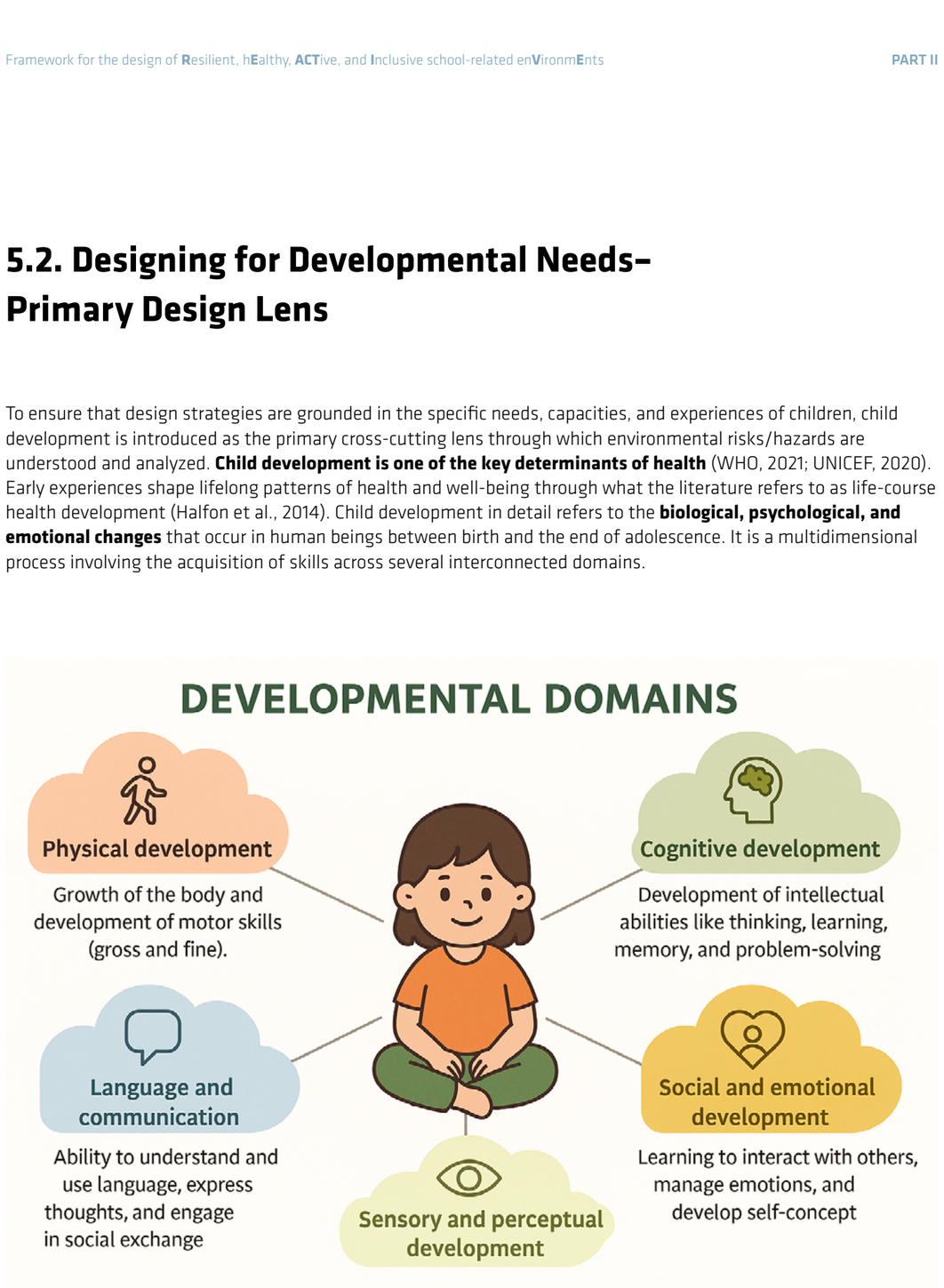


Figure 5.2. Child development domains.

Children's developmental needs evolve rapidly across life stages and are profoundly shaped by their everyday environments. Recent scientific literature highlights environmental exposures (air pollution, heat stress, noise exposure, limited access to green spaces, and unsafe infrastructure), social determinants (e.g., safety, inclusion, social cohesion), and behavioral factors (e.g., physical activity, nutrition) as key determinants of child health. Table 5.2.b synthesizes key determinants affecting child development, contextualizing them in school-related settings.

Table 5.2.b Hazards Impacting Child Development

Hazard	Impact on child development	Contextualised in schoolyards	References
Heat stress	Affects concentration, Physical comfort, Risk of dehydration or inactivity	Unshaded zones, heat-absorbing materials	Vanos et al., 2020; EPA 2016
Air pollution	Impairs cognitive function, increases the risk of asthma increases risk of reduced physical activity	Proximity to roads, poor vegetation buffering	Sunyer et al., 2015; WHO 2018
Noise pollution	Increases stress, reduces attention span, Negatively impacts language development	Proximity to traffic,Hard surfaces reflecting sound	Stansfeld & Clark, 2015
Biotope loss	Reduces biodiversity exposure, weakens the immune system, lowers ecological learning opportunities	Disconnection from urban green networks, sealed surfaces	Fjørtoft, 2001; Tzoulas et al., 2007
Lack of green space	Reduces opportunities for exploration, nature connection, and physical activity	Paved surfaces dominate, minimal vegetation	Dadvand et al., 2015; Chawla, 2015
Physical inactivity	Contributes to obesity, poor motor development, and low emotional regulation	Lack of affordances, minimal unstructured play options	Janssen & LeBlanc, 2010; Ginsburg, 2007
Spatial inequity	Limits autonomy, excludes children with disabilities and diverse needs; undermines confidence, learning, and participation	Street and crossing design, absence of ramps, tactile paths, multisensory cues, or flexible zones	UNICEF, 2013; Steinfeld & Maisel, 2012

Figure 5.2 Groenbluaw schoolyards, The Netherlands.

5.2.1 Age-Specific Needs and Spatial Implications

"Developmental stages define what environments children need and how they experience space."

Designing with development in mind means creating environments that stimulate curiosity, encourage autonomy, support emotional regulation, and provide opportunities for movement and interaction. It also means acknowledging the diversity of developmental trajectories, including those of children with disabilities, neurodivergent children, and children from different socio-cultural backgrounds. Child development evolves significantly from nursery to high school; a one-size-fits-all schoolyard cannot meet the needs of both younger and older children. Therefore, designing schoolyards must align with the age-specific developmental needs of children and adolescents. Each development stage requires tailored spatial and environmental responses. Table 5.2.1. provides a structured overview of the differences, emphasizing what is most important for each age group across key developmental domains.

For **nursery-aged children (0–3 years)**, rapid brain development, early motor skills, and sensory exploration are central. Spaces should offer crawl-friendly surfaces, enclosed shaded zones, and multisensory experiences like textures, water, and soft vegetation to promote safe attachment and early exploration.

During **preschool years (3–6 years),** children engage in symbolic play, socialization, and language development, with increasing mastery of gross and fine motor skills. Playhouses, manipulation materials (sand, water, natural elements), and climbing or balance structures offer both cognitive stimulation and physical challenges, while quiet corners support emotional regulation.

In the **elementary school phase (6–11 years),** children develop logical thinking, cooperative play styles, and greater physical coordination. Schoolyards should support both structured and unstructured play, with game courts, climbing nets, nature exploration zones, and group seating or outdoor learning spaces to enable social and cognitive development.

By **middle school (11–14 years)**, students value autonomy, peer interaction, and emotional privacy, with growing physical strength and identity exploration. Design should respond with flexible youth-oriented spaces, such as hangout areas, fitness installations, and sheltered zones that allow for self-directed use, as well as green spaces for emotional decompression.

Finally, **high school students (14–18 years)** face increasing academic pressures, emotional complexity, and a need for self-expression. Thoughtfully designed environments can offer outdoor study areas, recreational and multi-use zones, and opportunities for creative engagement, such as murals or participatory design spaces. Nature-rich elements, including trees and gardens, also serve as essential stress buffers during this stage.

Figure 5.2.1 Green classroom. (© Greenschoolyards America)

Table 5.2.1. The Age-Based Developmental Needs and Design Responses table summarizes the evolving cognitive, emotional, and physical needs of children by age, alongside the spatial characteristics that best support their development. Sources: Erikson (1950–1982); Piaget (1952); Bronfenbrenner (1979); Ginsburg (2007); Lester & Russell (2008); UNICEF (2021).

School level	Age range	Developmental characterictics	Supporting envrionments
Nursery	0–3 years	Rapid brain development; Sensory exploration; Attachment and emotional bonding; Early motor skills	Safe sensory environments (textures, water, plants); Crawl/toddler-friendly surfaces; Shaded and enclosed spaces; Gentle slopes, push toys
Kindergarten (Preschool)	3–6 years	Symbolic play, imagination; Language explosion; Socialization begins; Gross and fine motor development	Imaginative play zones (playhouses, role-play stations); Diverse materials for manipulation (sand, water, natural objects); Balance and climbing structures; Quiet areas for emotional regulation
Elementary School	6–11 years	Rule-based play; Developing logic and reasoning; Expanding peer interactions; Coordination and agility improve	Zones for cooperative and competitive play; Exploratory natural areas; Structured games (ball courts, climbing nets); Group seating and outdoor classrooms
Middle School	11–14 years	Abstract reasoning; Peer influence increases; Emotional intensity; Growing physical strength and independence	Flexible, youth oriented spaces (hangout areas); Sport courts, fitness equipment; Sheltered zones for autonomy and privacy; Green areas for stress relief
High School	14–18 years	Identity formation; Academic pressure; Increased autonomy; Social/emotional complexity	Outdoor study and reflection zones; Multi-use recreational areas (sports, relaxation); Nature-based stress buffers (trees, gardens); Opportunities for self-expression (murals, participatory design spaces)

Figure 5.2.2 Independen activties, Green schoolyardsAmerica.

5.2.2. Design Strategies Supporting Child Development Across All Ages

While the developmental needs of children evolve with age, several core design principles remain consistent in supporting healthy growth, play, and learning. This paragraph outlines a set of universal design strategies that apply across all childhood stages, from early years to adolescence.

Natural Play Elements over Commercial Equipment
Natural elements such as logs, boulders, vegetation, sand, and water enable diverse, open-ended play experiences. Unlike standardized commercial playground equipment, these elements promote imaginative, sensory-rich, and physically varied engagement. They also foster risk negotiation, motor development, and a connection to nature—beneficial across developmental stages. (Herrington & Brussoni,2015; Fjørtoft,2001; Chawla, 2015; Ginsburg, 2007)

Topographic and Textural Diversity
Introducing varied terrains—slopes, small hills, boulders, loose soil, grassy mounds—supports motor coordination, balance, and spatial awareness. Textural diversity underfoot (e.g., mulch, gravel, wood, grass) also stimulates sensory input and encourages exploration and diverse movement patterns for all age groups.(Fjørtoft, 2001; Dyment & Bell, 2008; Gill, 2014)

Sensory & Neurodiversity-Supportive Design
Inclusive schoolyard design must consider the needs of children with sensory sensitivities and neurodivergence (Floyd et al., 2020; Gallez et al., 2024; Kuo et al., 2019; UNICEF, 2021). This involves:

- Avoiding overstimulating elements (e.g., harsh noise, visual clutter),
- Providing sensory breaks and calm zones,
- Using tactile cues and varied textures for orientation,
- Ensuring gradients of stimulation across space (quiet K active).
- Nature-based features (e.g., water, leaves, bark, gentle soundscapes) offer passive sensory engagement without overstimulation.

Diversity of Social Spaces: Play and Retreat
The spatial diversity supports inclusion, emotional regulation, and different temperaments and social needs—especially relevant during middle childhood and adolescence (Dyment & Bell, 2008; Brussoni et al., 2015; Lester & Russell, 2008). Schoolyards must offer a range of spatial configurations that allow for:

- Large group interactions (e.g., open lawns, sport courts),
- Small group hangouts (e.g., seating circles, nooks),
- Solitary retreat (e.g., hideouts, garden corners, quiet benches)

Zoning for Varied Activity Levels
A universally applicable strategy is zoning—designing spaces according to levels of activity: quiet, semi-active, and active. This allows children to self-regulate engagement levels and ensures everyone can find suitable environments for play, learning, and rest. Zones should be visually connected but acoustically and physically buffered to prevent conflict and overstimulation. (Ginsburg, 2007; Moore & Wong, 1997; UNICEF, 2021; Brussoni et al., 2015)

Opportunities for Unstructured and Open-Ended Play
While most applicable to younger age groups, unstructured play opportunities benefit all children by encouraging creativity, self-direction, and social negotiation. Open-ended materials—like loose branches, fabric, sand, or modular elements—invite children to invent, build, and imagine. These materials support symbolic and constructive play and

can be adapted for older users (e.g., modular outdoor furniture, repurposed sports equipment).(Nicholson, 1971; Maxwell et al., 2008; Bundy et al., 2009; Brussoni et al., 2012)

Supporting Autonomy and Independence
A critical yet often under-addressed strategy in design is fostering children's independence. Autonomy is a developmental asset across all ages. At the micro scale, it is about enabling self-directed activity through child-scaled furniture, low barriers, and features like low windows for visual access. At the macro scale, autonomy connects to the ability to move freely and safely in one's environment, such as walking or biking to school (Malone, 2007; Karsten, 2005 ; Tranter & Pawson, 2009; UNICEF, 2018).

Although these strategies are universal, their implementation must be tailored to the specific needs, capacities, and interests of different age groups. Table 5.2.2. illustrates examples of how each strategy can be translated into age-appropriate design solutions.

Table 5.2.2. Application of General Design Strategies Across Age Groups illustrates how general design strategies can be adapted into age-appropriate solutions to meet the evolving developmental needs of children and adolescents.

Strategy	Nursery (0-3)	Pre-school (3-6)	Primary (6-11)	Middle (11-14)	High (14-17)
Natural Play Elements	Sand, soft vegetation, water basins	Logs, stumps, small nature zones for imaginative play	Exploration trails, tree areas, natural climbing features	Shaded green nooks, informal seating with trees	Gardens, edible plants, quiet natural buffers
Topographic & Textural Diversity	Gentle slopes, padded surfaces, leaf piles	Balancing logs, textured stepping paths	Varied terrain, climbing rocks, multi-surface sports areas	Multi-level seating, terrain-based fitness circuits	Outdoor stairs, amphitheaters, varied paving for informal use
Sensory & Neurodiversity Support	Tactile paths, soft noise zones, enclosed sensory pods	Water play, textured walls, gentle sounds from natural elements	Sensory paths, interactive walls, zones with contrast and calmness	Semi-enclosed green zones, tree-covered seating, shelter from overstimuli	Multi-sensory gardens, calming study zones with varied textures
Opportunities for Social Play & Retreat	Soft play corners, shaded cozy enclosures	Small group playhouses, semi-private dens	Outdoor classrooms, flexible seating in circles	Hangout pods, covered pergolas, group swings	Informal seating clusters, shaded rest areas, co-design murals
Autonomy & Independence	Low furniter, accessible areas	Self-service stations, reachable materials	Low chalkboards, open-access storage	Co-design areas, youth-only corners	Co-managed spaces

5.2.3. Indicators for Age-Responsive Design

To translate developmental principles into practical design and evaluation, this section presents key indicators for assessing how well schoolyard environments respond to the needs of different age groups, as shown in Table 5.2.3.

Next page: Table 5.2.3. Indicators for Age-Responsive Design.
**Benchmarks are indicative starting points drawn from the cited literature; they should be calibrated to local regulations and user consultation.*

Indicator	Why it matters	How to measure?	Suggested Benchmark (illustrative)*	References
Distinct spatial zones by age group (in case of different school levels)	Ensures toddlers, primary-age children, and adolescents each have environments scaled to their physical size, risk tolerance, and social needs.	• Site layout plan annotated by designers • Post-occupancy mapping of user distribution (15-min interval scans)	≥ 3 clearly demarcated zones on sites serving multiple age groups	UNICEF (2018); Moore & Cosco (2019)
Variety of physical affordances (climbable, balance, hang, hide, roll, kick, dig)	Supports motor-skill progression and prevents dominance of a single play type.	• Affordance inventory checklist • Photographic survey	≥ 7 affordance types in preschool yards; ≥ 10 in primary; ≥ 12 in secondary	Gibson (1979); Andersen et al. (2022)
Provision of natural loose parts (sticks, stones, leaves, sand, water)	Fuels symbolic play, creativity, sensory integration, and fine-motor refinement.	• Quadrat counts of loose-part density • Teacher log of replenishment	Loose-part density ≥ 15 items m² in early-childhood corners; ≥ 5 items m² in primary nature zones	Bundy et al. (2017)
Quiet / restorative micro-spaces	Enables self-regulation, small-group conversation, and stress recovery—critical for neurodiverse and adolescent users.	• Count of seating or refuge niches sheltered from main activity flow	≥ 1 quiet nook per 30 users; noise ≤ 55 dB(A) daytime	Moore & Cosco (2019); WHO (2018)
Shade and UV protection proportion (further detailed under urban heat)	Protects sensitive skin and enables longer outdoor stays, especially for ages 0–10.	• GIS canopy analysis + structure shade footprint	Minimum 50 % shade over early-childhood zone; 30 % over primary active zone	WHO (2016)
Surface diversity / texture ratio	Different textures aid balance training, proprioception, and sensory seeking.	• % of yard in turf, mulch, rubber, permeable paving, earth	At least 4 distinct surface types present	Fjørtoft & Sageie (2009)
Risk-benefit play elements (heights, loose logs, boulders)	Appropriate challenge supports confidence and risk competence.	• Risk/benefit audit form (UK Play Safety Forum)	Presence of graduated height elements (0.6 m–1.2 m preschool; 1 m–2.4 m primary)	Sandseter (2010) add ISO standards
Adolescent social autonomy features (Wi-Fi spots, seating clusters, murals)	Responds to identity formation and peer-bonding needs of 12-18-year-olds.	• Count of semi-enclosed seating clusters, creative expression walls	≥ 1 cluster / 20 students; ≥ 1 surface allocated for student art	Chawla (2015)
Accessibility / universal design score (further detailed under spatial inequity)	Guarantees inclusion of users with mobility, sensory, or cognitive differences across ages.	• EU / national checklist	90 % of zones meet accessibility criteria; zeroKstep entry to all main areas	Steinfeld & Maisel (2012)

Figure 5.3. Climate shelters project, Barcelona, Spain.

5.3. Designing for Climate Resilience

5.3.1. Climate-related hazards in School Environments

Climate change increasingly affects the daily lives of children in cities. Climate-related hazards, such as extreme temperatures, UV radiation, extreme precipitation, drought, and air pollution, interact with urban design features (e.g., asphalt surfaces, poor ventilation, and a lack of vegetation), thereby increasing health and well-being risks. Table 5.3.1. synthesizes the primary environmental drivers, direct and indirect health impacts, and relevant references for key climate-related hazards commonly affecting urban/school environments. These hazards manifest differently depending on local climate conditions, land use, materials, vegetation, and urban form. In urban contexts, as emphasized by Sebos et al. (2023), schoolyards often lack adaptive features that mitigate urban heat and flooding, thus becoming hotspots for thermal and environmental stress.

Table 5.3.1. Primary environmental drivers, direct and indirect health impacts, and relevant references for five major climate-related hazards commonly affecting school environments.

Climate-related hazard	Primary Environmental Drivers	Direct Health Impacts	Indirect Health Impacts	References
Urban Heat / UHI	Impermeable surfaces (asphalt); Lack of vegetation and shade; Building reflectance	Heat exhaustion, dehydration; Risk of heatstroke; Skin irritation from hot surfaces	Reduced physical activity and play; Cognitive fatigue; Sleep disruption due to thermal discomfort	Kanai & Fabio, 2022; Sebos et al., 2023
Solar Exposure & UV Radiation	Lack of shade structures; High surface reflectivity; Outdoor activity during peak hours	Sunburn; Increased skin cancer risk; Eye damage (UV exposure)	Avoidance of outdoor activity; Reduced engagement in outdoor learning due to glare and discomfort	Bratman et al., 2019; WHO, 2017
Stormwater Runoff & Flooding	Sealed/paved surfaces; Compacted soils; Inadequate drainage infrastructure	Injuries from slipping; Increased risk of mold-related illnesses; Contaminated water exposure	Reduced usability of outdoor space; Stress and anxiety due to perceived danger or limited access	Flax et al., 2023
Drought & Water Scarcity	Prolonged dry seasons; Decline in irrigation capacity; Heat stress on vegetation	Dehydration; Reduced hygiene access if water is scarce	Loss of greenery and shade; Psychological discomfort due to barren, unattractive settings	IPCC, 2023; Kanai & Fabio, 2022
Air Pollution Accumulation (Climate-exacerbated, not climate-caused)	Proximity to traffic and roads; Industrial emissions; Low vegetation cover	Respiratory issues (asthma, bronchitis); Headaches, throat irritation	Reduced outdoor activity; Impaired cognitive performance from long-term exposure	Flax et al., 2023; Gallez et al., 2024; WHO, 2022

5.3.2. Assessing climate-resilience in school-related environments

Climate resilience refers to the ability of urban systems, including built, social, and ecological components, to absorb, adapt to, and recover from climate-related shocks such as extreme heat, heavy rainfall, and flooding. In school-related environments, resilience is especially critical due to children's heightened vulnerability and their frequent exposure to outdoor conditions.

Drawing from the IPCC AR6 Risk Framework, climate-related risk is defined as a function of:

Risk = Hazard × Exposure × Vulnerability (IPCC, 2022)

Based on this, climate resilience is closely linked to reducing exposure and vulnerability while strengthening adaptive capacity. To evaluate climate resilience in school-related urban environments, five overarching criteria are extrapolated from the IPCC framework and proposed as shown in 5.3.2. table.

Table 5.3.2.

Criteria	IPCC Component	What it captures
Risk Exposure	Hazard × Exposure	Identifies climate hazards (e.g., heat, flooding) and the spatial zones/users most affected
User Vulnerability	Vulnerability	Captures age- and physiology-related sensitivity to climate stress (e.g., metabolism, comfort)
Spatial and Material Resilience	Adaptive Capacity	Evaluates the ability of materials, orientation, and layout to reduce heat and manage stormwater
Ecological and Green Capacity	Adaptive Capacity	Assesses Nature-based systems that regulate climate extremes (e.g., evapotranspiration, infiltration)
Emergency Readiness & Management	Adaptive Capacity	Assesses governance, maintenance, and preparedness mechanisms

The multi-criteria approach allows for a comprehensive evaluation of climate resilience in school-related environments. By systematically considering both physical and physiological vulnerabilities, and integrating performance-based and observational metrics, the framework supports both risk identification and informed design interventions.

A key focus of the framework is vulnerability, particularly in relation to children's physiological sensitivity to heat. Due to their higher surface-area-to-mass ratio, lower sweat production, and immature thermoregulation systems, children are significantly more susceptible to heat stress. This vulnerability is amplified during physically active periods such as recess or physical education, when metabolic heat production increases, raising the body's thermal load.

In this context, outdoor comfort becomes a vital dimension of climate resilience. Microclimatic conditions, such as solar radiation, wind, surface temperature, and humidity, interact with a child's metabolic response, and are directly shaped by spatial design decisions involving shade, airflow, surface materials, and vegetation.

By embedding thermal comfort and metabolism within the vulnerability criterion, the framework highlights the need for child-centered climate adaptation. Ensuring thermally safe and comfortable environments is essential to support children's health, learning, and daily routines, especially under increasing climate pressures.

"Children do not regulate their temperature as efficiently as adults and are therefore more vulnerable to outdoor thermal stress, particularly in poorly shaded, heat-retaining environments." (Kenney et al., 2014; Vanos et al., 2016)

Type of difference	Internal sources of difference	External sources of greater sensitivity
Metabolic	Greater respiratory rate Greater metabolic rate Greater water demand per unit of body mass	Air pollution, allergens Malnutrition, thermal extremes Gastrointestinal illnesses, dehydration
Behavioural	Greater outdoor time Greater vigorous activity Less ability to avoid unhealthy situations Less ability to swim	Infectious diseases, air pollution, ultraviolet (UV) radiation, thermal extremes, allergens UV radiation, thermal extremes Drowning
Physiological	Greater surface areas Less detoxifying capacity Less skin development Reduced immunity	Air pollution, UV radiation Infectious diseases, Air pollution, UV radiation UV radiation thermal extremes Infectious diseases, allergens, mycotoxins
Temporal	Greater latency for genetic/long-term effects	UV radiation, malnutrition, allergens
Developmental	Undergoing development	Malnutrition, psychosocial trauma, morbidity and quality of life compromised

Figure 5.3.2. Difference between children and adults in vulnerability to the effects of the climate change. Source: WHO Regional Office for Europe, 2008.

Considering children's high vulnerability to heat and physiological differences based on age and gender it is important to further explore the key factors influencing outdoor comfort.

Outdoor thermal comfort refers to how temperature, solar radiation, wind, and humidity combine to create perceived conditions in outdoor environments. For children, whose activity levels are high and heat tolerance lower, thermal comfort strongly influences whether schoolyards are usable, safe, and developmentally supportive during warm seasons. Therefore, outdoor comfort can be framed as a spatial performance goal that determines whether children can safely and enjoyably use outdoor space under heat stress. It is a key performance criterion for climate-adaptive design as it:

- is measurable (ENVI-met, surface temps, shade levels)
- design-relevant (linked to material, shade, orientation)
- ties directly to children's experience of play, rest, and learning.

Themal comfort depends on various parameters, from objective ones, such as air temperature, relative humidity, and mean radiant temperature, to subjective parameters including metabolic rate and clothing insulation.
These physiological factors, especially metabolism, are closely tied to children's activity levels and age-specific thermoregulation. As such, understanding relationship between metabolism and climate provides deeper insight into how children experience thermal environments and how design can mitigate heat-related vulnerability.

Children's higher metabolic rate and less efficient thermoregulation means they generate and retain more heat during physical activity, making them more sensitive to warm outdoor conditions. This physiological difference reinforces the need for shaded, cool, and rest-oriented microzones during warm periods in schoolyard design.

Observing the common schoolyard design, and in particular the activity zones (e.g. ball courts, climbing nets, running loops), it is interesting to note that these areas are often in the sun, surfaced with black rubber or asphalt, and lacking shade, seating, or rest stops.
Considering that the children are generating the most heat during activity further sun exposure adds heat stress to their bodies. This is one example of a design contradiction: the areas where children need cooling the most, are the hottest ones. To avoid heat stroke and reduce the negative impact of climate and other environmental hazards, the design must be able to anticipate and balance these kinds of contradictions.

5.3.3. Key determinats and Indicators for Climate Resilient school-related environments

Starting from previously identified five assessment criteria: 1) risk exposure, 2) user vulnerability, 3) spatial and material resilience, 4) ecological capacity, and 5) emergency and readiness management,
following indicators were select to support performance-based evaluation and guide evidence-informed design interventions that reduce risk, enhance comfort, and promote well-being.

Figure 5.3.3 Climate Shelters project, Barcelona, Spain.

Table 5.3.3. Indicators for Climate Resilience in School-Related Urban Environment.

Indicator	Metric	Methodology	Purpose
Climate hazard exposure mapping	UHI index, heatwave frequency, flood risk zone	GIS overlay of satellite data, city risk maps	Identify baseline climate hazards and spatially contextualize risk
Air quality and pollution exposure	PM2.5 / NOK concentration levels	Local air quality station data or modeling	Understand additional exposure risks relevant to child health
Weather event frequency	Days/year over 30°C or high rainfall intensity	Meteorological data analysis	Quantify recurrence of stress-inducing climate events
Surface materials	Type and reflectivity (e.g., dark asphalt vs. light pavers)	Visual audit, thermal imagery	Understand heat retention and UHI potential
Shade availability	% shaded area during peak hours	Site mapping, sun path analysis	Determine protection from heat and UV exposure
Building layout and height	Canyon effect and ventilation	Morphological analysis, airflow modeling	Assess heat trapping and airflow potential
Airflow	Presence of ventilation corridors or stagnant zones	Wind tunnel testing, field observation	Determine microclimatic ventilation
Surface permeability	% permeable vs. impermeable area	Ground survey, material inventory	Estimate stormwater absorption and surface cooling potential
Drainage and slope	Drainage system quality, surface gradient	Visual inspection, topographic analysis	Assess water management and pooling risks
Curb and gutter design	Functionality and maintenance status	Field inspection	Determine stormwater redirection capacity
Erosion and water damage	Visible damage and wear from past rainfall	Visual observation	Identify past failure points and maintenance needs
Thermal comfort (children)	UTCI or PET index by age group	On-site measurements, microclimate models	Assess outdoor safety for children under varying activity levels
Physical activity and heat load	MET equivalents, activity zones overlap with hot spots	Observational mapping, activity logs	Identify risk from compounded exposure due to movement
Thermoregulatory vulnerability by age	Proxy based on age demographics	School data, behavioral patterns	Account for physiological vulnerability in design decisions
Gender-sensitive exposure differences	Metabolism, clothing, activity type, spatial behavior	Interviews, ethnographic observation	Address differential risks and design needs by gender
Ecosystem performance	Tree cover %, evapotranspiration, biodiversity	NDVI analysis, species count, canopy mapping	Capture regenerative and buffering capacity
Maintenance and emergency response	Presence of protocols, readiness plans, infrastructure upkeep	Policy review, interviews	Evaluate adaptive capacity in response to climate shocks

5.3.4. Climate-Responsive Strategies

Both climate mitigation and adaptation strategies are crucial for safeguarding health and well-being in the face of accelerating environmental change. In addition to reducing climate risks, many adaptation and mitigation strategies deliver significant health co-benefits. For example, promoting active travel (e.g., walking, cycling) not only reduces carbon emissions but also supports cardiovascular health and helps prevent obesity. Similarly, increasing urban greenery can mitigate heat and air pollution while enhancing mental well-being and biodiversity. While broad mitigation actions, such as reducing fossil fuel use and protecting ecosystems, remain essential, this thesis focuses on local adaptation strategies. These interventions complement mitigation efforts by addressing immediate climate impacts and improving everyday health conditions.

Nevertheless, it is important to mention the key mitigation strategies that benefit public health:

- Reducing fossil fuel combustion, which improves air quality.
- Transforming urban transport; eg, promoting public transport use, implementing 30km streets, etc.
- Encouraging active mobility; eg, activating pedibus or ciclovia to promote active travel to school, ensuring pedestrian paths and crossings are safe for children, etc.
- Preserving and expanding green infrastructure, serving as carbon sinks and biodiversity habitats; eg, creating green corridors along pedestrian routes to school, etc.
- Improving access to natural spaces, particularly for children and vulnerable groups.

Alongside these, adaptation strategie, such as Climate-sensitive design and Nature-based Solutions help cities respond to local risks while creating healthier, more resilient environments. Importantly, adaptation measures have the potential to foster not only human well-being but also ecological health. However, their benefits are often underexplored, especially in terms of addressing the diverse needs of specific populations such as women, children at different developmental stages, adolescents, and the elderly. Effective adaptation must therefore move beyond generic solutions and actively support inclusive, health-promoting environments that respond to the needs of all living beings.

The Figure 5.3.4 illustrates how simple and smart spatial interventions, such as shading and vegetation, can significantly reduce heat stress and improve outdoor comfort, particularly for sensitive users.

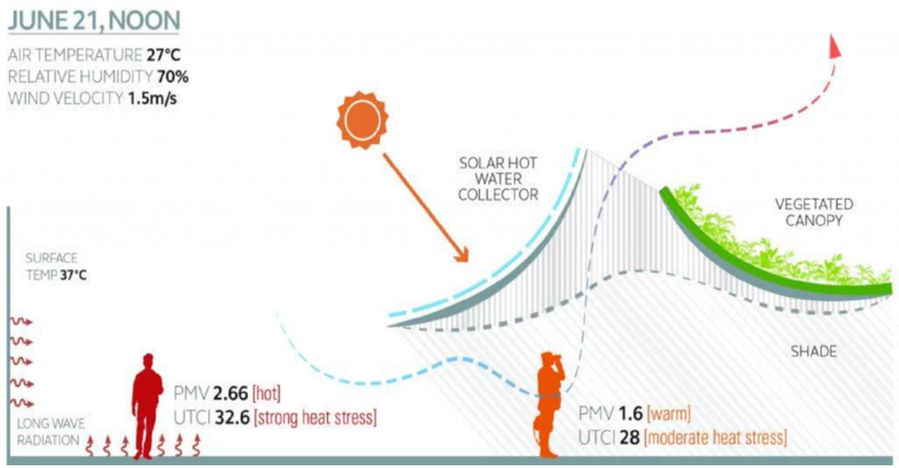


Figure 5.3.4. Impact of Vegetation and Shade on Outdoor Thermal Comfort

Comparison of PMV and UTCI values in sun-exposed and shaded areas under identical climatic conditions (air temperature 27°C, relative humidity 70%, wind velocity 1.5 m/s). The vegetated canopy and shading structure reduce thermal stress from strong heat stress (UTCI 32.6) to moderate (UTCI 28), demonstrating the value of climate-adaptive spatial design.

Designing for climate resilience in schoolyards involves integrating microclimate-sensitive and hydrologically functional features. As the figure illustrates, integrating shade structures and vegetation can substantially improve outdoor thermal comfort. Translating such principles into schoolyard and urban design requires a toolkit of actionable, site-sensitive strategies. The following Table 5.3.4 summarizes key spatial interventions that address both climate risks and health-related outcomes, with attention to their usability and ecological performance.

Table 5.3.4. Climate responsive design strategies.

Strategy	Climate function	Design note
Tree planting and vegetated zones	Shade, evapotranspiration, cooling	Select native or drought-tolerant species; protect root zones
Permeable and light-colored surfaces	Reduce heat gain, manage runoff	Use gravel, wood chips, or permeable concrete in activity areas
Green roofs / wall surfaces	Reduce building heat load, storm buffering	Potential for learning zones if accessible
Blue-Green Infrastructure / Rain gardens / bioswales	Infiltrate stormwater, support biodiversity	Can double as sensory zones with careful planting
Water fountains and misting stations	Hydration, cooling during peak heat	Ensure accessibility and hygiene
Shaded seating and rest zones	Thermal comfort and recovery	Combine tree shade and pergolas with movable elements

5.3.5. Final considerations

While this chapter focuses on the risks posed by climate-related hazards such as urban heat, flooding, and drought, it is important to acknowledge the key role of Nature-based Solutions (NbS) in mitigating these challenges. NbS with their capacity to regulate microclimate, manage water, and enhance environmental quality represent a core set of strategies within climate-resilient design.

Equally important, climate-resilient design must respond to human physiological needs, particularly the heightened vulnerability of children. Factors such as outdoor thermal comfort and metabolic heat production during physical activity directly influence whether school-related environments remain safe, healthy, and usable under heat stress.

Given their multifunctional nature, and to avoid redundancy, a detailed discussion of NbS, including their climate, ecological, and child development benefits, is presented in Section 5.4.4. This section consolidates relevant solutions and highlights their potential to simultaneously address climate risks, restore ecological functions, and support children's well-being in school-related environments.

Figure 5.4. Greenschoolyards America.

5.4. Designing for Biotope Restoration

5.4.1 Biotope Loss and Its Health Impacts on Children

The loss of natural ecological systems, especially in cities due to heavy urbanization and climate change, is not only a climate and environmental issue but also a public health concern (Bratman et al., 2019; Soga et al., 2021). One way to approach this phenomenon is through the concept of a biotope. Defined by Mirriam Webster as "a specific area characterized by uniform environmental conditions and hosting distinct communities of plants and animals, forming a habitat within a broader ecosystem", biotop consistis of abiotic components (soil, water, climate, light), biotic interactions (plant and animal life), and spatial characteristics (layout, layering, connectivity).

Biotope loss occurs as a result of the degradation, fragmentation, or complete removal of these living environments, mainly due to the urbanization, ultimately leading to:

- **Biodiversity loss:** species extinction or reduction (Soga et al., 2016; Sanz-Mas et al., 2023)
- **Disruption of ecological services:** pollination, air filtration, water retention, soil health (Giezen & Pellerey, 2021; Rook, 2013)
- **Reduced environmental resilience** against heat, flooding, diseases (Sebos et al., 2023; Kanai & Fabio, 2022)
- **Decline in human–nature interactions**, especially for children and vulnerable groups (Tillmann et al., 2018; Floyd et al., 2020)

These combined impacts not only affect ecosystem health but also diminish opportunities for sensory engagement, emotional restoration, and cognitive development, particularly in children and vulnerable populations (Bratman et al., 2019; Soga et al., 2021).

In densely urbanized areas, schoolyards sometimes present the only accessible point of contact with nature in children's daily lives. Yet, many of them are ecologically sterile: paved, mono-functional, and lacking biodiversity (Flax et al., 2023; Sebos et al., 2023). The lack of natural elements has profound implications for child well-being, potentially increasing stress levels, reducing attentional capacity, weakening immune development, and limiting opportunities for motor, cognitive, and socio-emotional growth (Roslund et al., 2020; Rook, 2013; Andersen et al., 2022), ultimately impacting not only their well-being but also their environmental literacy and long-term resilience.

Table 5.4 outlines, which and how specific forms of biotope degradation can lead to both direct health impacts and broader developmental consequences in children.

Table 5.4. Biotope Loss – Direct and Indirect Health Impacts on Children

Primary Environmental Driver	Biotope Degradation Factor	Direct Health Impact	Indirect Health and Development Impact	References
Paving of natural surfaces; monoculture turf use	Lack of vegetation and soil diversity	Reduced microbial exposure weakens immune system development	Limited nature interaction reduces attention restoration, stress reduction, and emotional regulation	Bratman et al., 2019; Rook, 2013; Giezen & Pellerey, 2021
Simplified landscapes; poor ecological planning	Absence of habitat variety (e.g., shrubs, logs)	Lower biodiversity exposure linked to allergies and autoimmune risk	Fewer sensory stimuli impair sensory integration and curiosity-driven learning	Flax et al., 2023; Sanz-Mas et al., 2023; Roslund et al., 2020
Tree removal; lack of replanting policies	Loss of tree canopy and vegetated shade	Increased UV exposure and elevated surface temperatures	Reduced shade limits outdoor use, physical activity, and social interaction	Sebos et al., 2023; Kanai & Fabio, 2022; Armson et al., 2013
Sealed surfaces; no space for ecological learning zones	Limited access to edible gardens or pollinator zones	Lack of direct experience with nature's cycles and food systems	Weakens environmental literacy, science learning, and sense of stewardship	Andersen et al., 2022; Floyd et al., 2020; Soga et al., 2016

5.4.2. Evaluating Biotop Loss

Evaluating biotope loss requires the integration of multiple scientific disciplines, including ecology, urban planning, and climate science (Kabisch et al., 2016; Gill et al., 2007). It relies on both qualitative and quantitative methods and indicators. Given the living, complex, and dynamic nature of biotopes, their assessment presents a significant methodological challenge (Giezen & Pellerey, 2021).

Considering the research scope (school-related environments), objectives (applied design and evaluation), and target user groups (public administration, practitioners, and school community), the research proposes five criteria for evaluating biotope loss that correspond to well-established ecological metrics supported by scientific references. The five criteria for evaluating biotope loss include:

1. **Green coverage** is used to assess the total amount of green space present within a specific area. The green-to-grey ratio is often used to quickly evaluate the balance between vegetated and impervious surfaces, providing an indicator of ecological performance, microclimate regulation potential, and overall landscape permeability (Flax et al., 2023; Gill et al., 2007).
2. **Green availability** evaluates the accessibility of green spaces to the population. For example, an urban area can be rich, but it may be private or enclosed within schoolyards available only to children, not to the broader community. In the schoolyard context, it can reflect the accessibility of the green space to children with disabilities (Soga et al., 2016; Andersen et al., 2022).
3. **Green connectivity/fragmentation** evaluates how well green spaces are connected and integrated with each other, facilitating the movement of species and the flow of ecosystem services across an urban area. This is particularly relevant for species migration and the functioning of ecosystems (Giezen & Pellerey, 2021; Soga et al., 2021).
4. **Green diversity** refers to the variety of plant species and habitat types within urban green spaces. When combined with the assessment of animal presence, it forms a foundational baseline for evaluating local biodiversity (Roslund et al., 2020; Rook, 2013).
5. **Animal presence** assesses the presence and abundance of wildlife within urban green spaces (Giezen & Pellerey, 2021).

5.4.3. Determinants of Biotop Loss and respective Indicators

While the proposed evaluation criteria help assess the condition of a biotope within a specific area, it is equally important to understand why biotope loss occurs and which underlying spatial and design-related factors shape these conditions. As previously illustrated in Table 5.4.1, a range of environmental factors and design decisions contribute to biotope degradation.

Moreover, considering that the ultimate objective of this research is to develop a practical framework and toolkit for evaluating and transforming schoolyards, it is essential to translate the ecological principles into spatial and design-relevant terms. Therefore, the key determinants of biotope loss with a focus on spatial and material-related aspects directly influenced by spatial design have been collected and synthesized in the following Table 5.4.3.
The table also introduces a corresponding set of indicators that serve to guide both design, ante and post evaluation. Together, the determinants and indicators provide a measurable basis for understanding and assessing ecological quality of school-related environments.

Table 5.4.3. Biotope Loss Determinants and Indicators.

Biotope Loss Determinant	Criteria	Ecological relevance	Design Relevance	What to Observe / Mesaure
Surface sealing / soil coverage	Green coverage	Prevents soil respiration, microbial activity, and vegetation growth	Overuse impervious materials in open spaces	% vegetated vs. impervious surface (visual estimate or GIS if available)
Lack of ecological layering	Green diversity	Monocultures offer limited niches for species	Flat grass-only spaces; no understorey or canopy	Presence or absence of vertical vegetation structure (groundcover, shrubs, trees)
Fragmentation and isolation	Green connectivity / fragmentation	Disconnected patches block species movement and gene flow	Small green areas/ pockets without corridors or stepping stones	Presence of connected or isolated patches (e.g., tree lines, hedges), tree tops interconnect
Topographic simplification	Green diversity / connectivity	Reduces microhabitat variation	Uniform grading; no natural features retained	Presence of varied terrain (mounds, logs, depressions, microhabitats)
Synthetic surfaces (plastic turf, rubber)	Green coverage	Sterile and heat-retaining; hostile to life	Often used for low-maintenance play or sports areas	Presence of synthetic vs. natural surfaces
Non-native or ornamental planting	Green diversity	Limited ecological value; weak support for native fauna	Chosen for aesthetics over function	Dominance of ornamental vs. native plants
Compact soil layers	Green coverage	Limits root growth, water retention, and soil life	Soil typology or caused by machinery or poor site preparation	Soil compaction visible; poor drainage; root penetration issues
Intensive maintenance (mowing, pesticide use)	Green diversity / Wildlife presence	Disrupts ecological cycles; removes microhabitats	Aesthetic-driven or safety-prioritized care	Signs of over-pruning, pesticide use, lack of flowering or deadwood
Lighting & noise pollution	Wildlife presence	Disorients or drives away pollinators and nocturnal species	Over-lighting of outdoor spaces or artificial noise	Artificial lighting at night, loud mechanical noise
Monofunctional zoning	Green availability / Wildlife presence	Restricts habitat diversity and multifunctional use	No overlap between ecological and human functions	Presence of spaces used only for single functions (e.g., only circulation or sports)

5.4.4. Key Strategies for Biotope Restoration

The analysis of determinants and corresponding indicators has identified several shortcomings that can be effectively addressed through targeted design strategies. To effectively restore ecological function and ecosystem services in an urbanised context, superficial greening measures or isolated planting efforts driven by aesthetic or certification goals are insufficient (Sebos et al., 2023; Sanz-Mas et al., 2023).

Design, instead, should involve intentional, ecologically grounded strategies that support local biodiversity and provide children and the wider community with opportunities for multisensory, exploratory engagement with nature, which contributes positively to human health and wellbeing (Bratman et al., 2019; Andersen et al., 2022). The following strategies, presented in Table 5.4.3, have been identified as effective responses to the main design-related causes of biotope loss. They offer practical approaches to restoring ecological value while supporting child development and health (Flax et al., 2023; Kabisch et al., 2016).

Table 5.4.4. Design strategies fo Biotope Recovery.

Strategy	Ecological Implication	Design Application
1. Ecological Layering	Incorporate multi-layered vegetation (groundcovers, shrubs, trees) to mimic natural habitats and increase ecological resilience.	Native planting in schoolyards, green corridors along streets, hedgerows on perimeters, buffer zones between school and street.
2. Pollinator and Habitat Support	Integrate flowering plants, insect hotels, deadwood, and birdhouses to foster biodiversity.	Pollinator gardens, log piles, vertical habitats, climbing plants on fences.
3. Edible and Interactive Planting	Link ecology with education through food-producing landscapes and student-managed gardens.	Raised beds, herb spirals, fruit trees in courtyards or small edges.
4. Green Infrastructure Integration	Combine ecological and hydrological functions to support biodiversity and stormwater regulation.	Bioswales, rain gardens, permeable planting strips near entrances, water retention gardens.
5. Soil Regeneration and Protection	Preserve living soil systems by minimizing compaction and enhancing microbial health.	Mulching, compost zones, soft transition spaces with permeable soil, root zones protected from trampling.
6. Topographic Diversity	Create varied terrain and microhabitats to foster biodiversity and stimulate children's exploration.	Mounds, sunken gardens, rocky edges, log or brushwood piles, shaded/restorative corners.
7. Microhabitat Creation	Include features that provide refuge and breeding ground for insects, birds, and small mammals.	Stone piles, leaf litter zones, wildflower meadows, shaded understory zones.
8. Connectivity with Wider Green Networks	Design for ecological permeability beyond the school boundary to support species movement and ecosystem services.	Tree-lined paths, ecological corridors, green median strips, planted pedestrian links to nearby parks.
9. Seasonal and Successional Design	Allow natural dynamics, seasonal change, and plant succession to occur, supporting ecological processes.	Low-intervention zones, areas left to flower and seed, wild planting that changes over time.
10. Multifunctional Ecological Zones	Combine biodiversity support with social or educational use.	Outdoor classrooms in forested corners, reading areas surrounded by herbs, nature play zones.
11. Sensory and Exploratory Nature Zones	Enable children to engage directly with loose, wild, and living materials.	Logs for climbing or sitting, sand and soil patches, quiet corners with dense planting.

Figure 5.4.4 Insect hotel.

5.4.5. Nature-based Solutions: adaptation and restoration tools

Nature-based Solutions (NbS) have emerged as powerful, systemic tools for addressing a wide range of urban challenges. Their multifunctional character makes them particularly relevant in the regeneration of schoolyards and school-related environments, where they offer integrated responses to environmental hazards, biotope loss, and children's developmental needs.

Defined by the European Commission as "*solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience,*" NbS play a central role in fighting negative effects of climate change, environmental hazards, biotope loss, and urbanization.

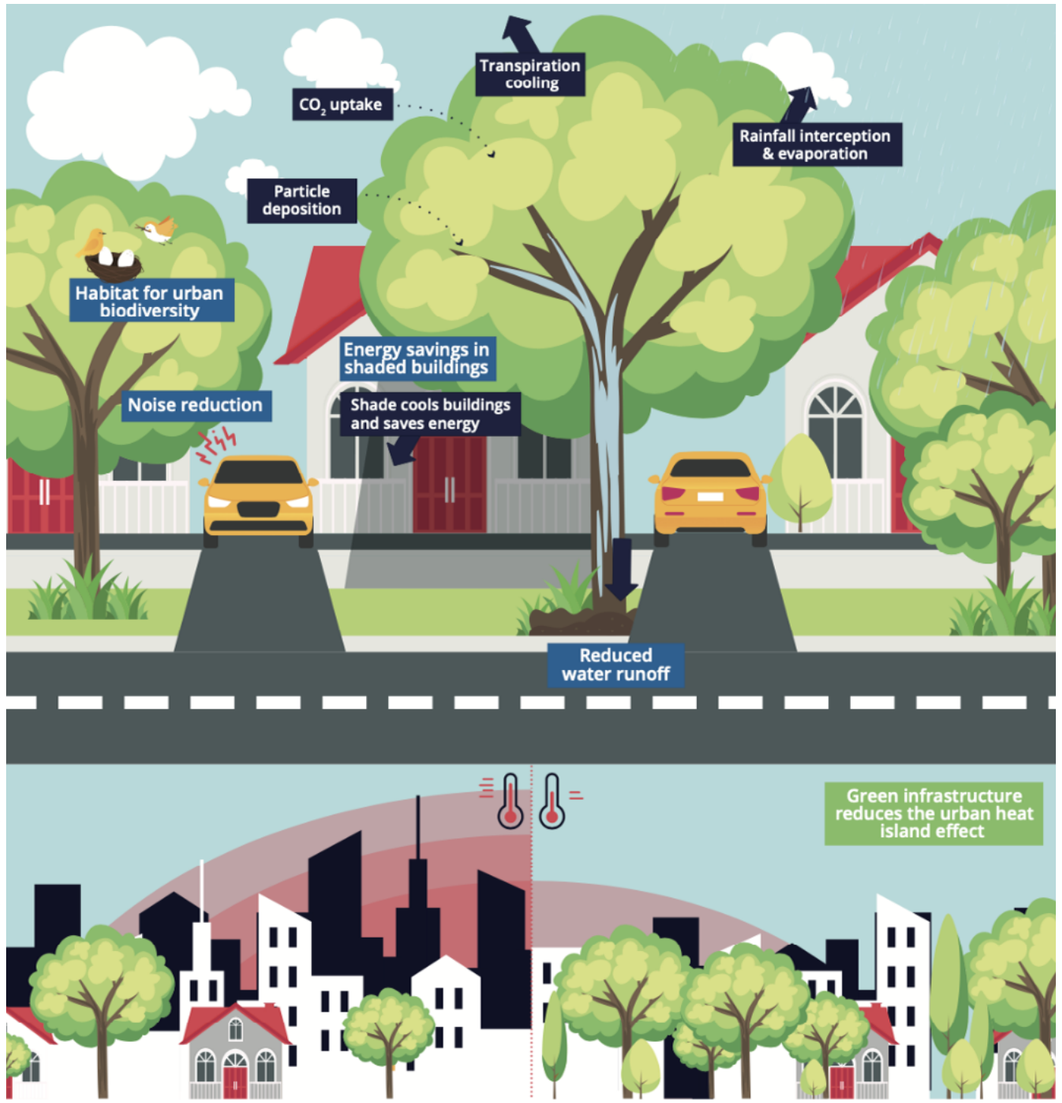


Figure 5.4.5. Example of the benefits of Green Infrastructure. Source: EEA.

The presented content is the result of an extensive literature review of peer-reviewed scientific articles, policy documents, design guidelines, planning toolkits, and implementation handbooks focused on NbS in urban contexts. Based on this review and aligned with the overall aim of this doctoral work, the results presented here demonstrate the multifunctional benefits of NbS, with a particular focus on their potential for enhancing climate resilience, promoting ecological restoration, and positively impacting health and well-being.

A growing body of research demonstrates the effectiveness of NbS in mitigating climate and environment-related hazards, thus increasing urban resilience and reducing the negative effects on children's health and well-being. Key NbS benefits in relation to climate resilience and hazard mitigation are:

- Urban Heat Mitigation: Vegetation and water elements reduce both surface and air temperatures through shading and evapotranspiration, enhancing thermal comfort and reducing the risk of heat-related illnesses (Bowler et al., 2010; Aram et al., 2019; Klemm et al., 2015).
- Stormwater Management: Green infrastructure, such as rain gardens, bioswales, and permeable paving, attenuates stormwater runoff, improves drainage, and reduces flood risk during extreme rainfall (Demuzere et al., 2014; Fletcher et al., 2015).
- Drought Resilience: The use of drought-tolerant plant species, mulching, and soil regeneration techniques improves water retention and contributes to microclimatic cooling (Kabisch et al., 2016).
- Air Quality Improvement: Dense vegetation, green walls, and tree canopies trap particulate matter and absorb pollutants, improving the air around schools (Abhijith et al., 2017; Baró et al., 2019).
- Noise Attenuation: Vegetated barriers—such as hedges and green mounds—act as buffers against traffic and playground noise, supporting better concentration and reduced stress (Gidlof-Gunnarsson & Öhrström, 2007).

In addition to climate regulation, NbS play an important role in ecological restoration by addressing the drivers of biotope degradation, particularly relevant for highly urbanised areas. In this context the school-related environments can serve as urban micro-biomes that restore biotope loss while supporting children's health and developmental needs. Key benefits for restoring biotope include (but are not limited to):

- Habitat provision and layering: Biodiverse planting schemes that incorporate multiple vegetation layers (groundcover, shrubs, trees) offer shelter, food, and breeding sites for a variety of species (Tzoulas et al., 2007; Gill et al., 2007).
- Ecological connectivity: Hedgerows, green corridors, and stepping-stone habitats reconnect fragmented patches, enabling species movement and gene flow (Benedict & McMahon, 2006; Giezen & Pellerey, 2021).
- Soil regeneration and water retention: Depaving, composting, and green infrastructure restore degraded soils and improve ecological capacity at the ground level (Demuzere et al., 2014; Wania et al., 2014).

Due to its multifunctionality, implementing NbS in school-related environments has high potential to improve the environmental quality and reduce children's exposure to various hazards. Carefully thought-out and bio-based inspired spatial design can positively influence children's physical, emotional, and cognitive development. Following are some of the positive outcomes of NbS for children's well-being:

- Biodiversity and Nature Deficit: Biodiverse environments support immune system development, promote psychological restoration, and encourage physical activity and unstructured play (Gill et al., 2007; van den Bosch & Sang, 2017).
- Cognitive stimulation: Diverse and sensory-rich environments support attention restoration, symbolic play, and nature-based learning (Lester & Maudsley, 2007; Herrington et al., 2007).
- Emotional regulation: Regular exposure to natural environments has been shown to reduce cortisol levels and support psychological resilience (Bratman et al., 2019; Soga et al., 2021).
- Physical development: Green and loose-part play areas encourage movement, gross motor skill development, and risk-benefit exploration (Fjørtoft & Sageie, 2000; Dyment & Bell, 2008).

- Biodiversity literacy and stewardship: Hands-on experiences with plants, insects, and ecological systems support climate awareness and pro-environmental behaviors (Chawla, 2015; van den Bosch & Sang, 2017).
- Community resilience: Green schoolyap-[=rds also function as neighborhood assets, providing shared, restorative space for families–especially in underserved areas (Wolch et al., 2014).

In conclusion, NbSs represent a powerful tool in addressing urban climate and environmental challenges. They provide multifunctional benefits across domains–reducing risks, supporting public health, improving environmental quality, and restoring ecological balance. The strength of NbSs lies in their systemic nature, offering services that span heat regulation, flood control, air and water purification, and biodiversity enhancement, while also creating more livable, inclusive spaces.

A selection of NbS solutions most relevant for school-related environments is collected and presented in Table 5.4.4. The solutions selected prioritize ecological restoration and child development alongside climate adaptation, offering multiple co-benefits through relatively low-cost, systemic interventions.

Table 5.4.5. Nature-based Solutions: Cross-Benefits for Climate Resilience, Biotope Restoration, and Child Development

NbS	Climate Hazard Addresses	Biotope Function Restored	Child Benefit
Rain Gardens	Flooding, stormwater runoff	Infiltration, habitat patches	Sensory play, water cycle learning
Green Roofs / Walls	Urban heat, air pollution	Thermal regulation, pollinator habitat	Microclimate control, biodiversity observation
Tree Canopy Planting	Heat, air quality	Shading, evapotranspiration, nesting	Outdoor comfort, cognitive recovery
Meadows / Habitat Patches	Biodiversity loss	Shelter, food, and reproduction sites	Spontaneous play, curiosity, science literacy
Edible Landscapes	Drought, soil degradation	Soil regeneration, plant diversity	Engagement with food cycles and sustainability
Swales	Flooding, runoff pollution	Water absorption and filtration	Safer access routes, visible environmental process
Wetland / Seasonal Ponds	Flooding, biodiversity loss	Amphibian habitat, water retention	Observation of life cycles, sensory exploration
Pollinator Gardens	Biodiversity loss	Support for bees, butterflies, etc.	Emotional well-being, nature learning
Unstructured Nature Zones	All hazards	Microhabitats, ecological layering	Risk-benefit play, motor development, regulation
Hedgerows / Green Corridors	Connectivity, noise	Species movement, edge habitat	Environmental literacy, quiet refuge

Note: *Solutions listed exclude grey solutions (e.g., cool pavements or synthetic turf) and focus on nature-inspired measures that actively restore living systems while enhancing health and developmental potential.*

5.4.6. Final considerations

Contextualized in schoolyards, NbS not only serve to mitigate environmental and climate risks, but also provide co-benefits aligned with child development, such as improved attention, reduced stress, and opportunities for social interaction and physical activity. Furthermore, naturalistic environments with uneven terrain, loose parts, and interactive features promote motor development, free play, and physical engagement (Dyment & Bell, 2008; Herrington et al., 2007).

However, despite their benefits, implementing and sustaining ecologically rich schoolyards requires careful attention to context and long-term viability in particular regarding:

- **Maintenance**: Ecological features often require seasonal care and cannot be fully managed by custodial staff. Partnerships with environmental organizations, parents, or older student groups can help distribute responsibility.
- **Safety and Liability:** Natural materials like logs, boulders, and uneven terrain may raise concerns over injury. Clear communication and a risk-benefit approach can help shift perceptions and reduce overregulation.
- **Plant Selection and Health Considerations**: The ecological and functional performance of NbS is highly dependent on the use of appropriate plant species. Selecting vegetation that aligns with local climate, soil conditions, and hydrology improves survival rates and reduces irrigation needs. In addition, it is essential to assess species for potential allergenicity (e.g., high-pollen trees), invasive behavior, or root systems that may damage infrastructure. Preference should be given to native or climate-resilient species that support biodiversity while minimizing maintenance and health-related risks (Masi et al., 2021; Aronson et al., 2017).

Figure 5.4.6 SUDs planter in Climate Resilient Schools in London, UK.

Figure 5.5.Groenbloauwe schoolplein, The Netherlands.

5.5. Designing for Physical Activity

The World Health Organization (WHO) defines physical activity as "any bodily movement produced by skeletal muscles that requires energy expenditure" (WHO, 2022). It includes a broad range of structured and un-structured activities; for children and adolescents, physical activity refers to all movement, including play, games, sports, transportation (e.g., walking, cycling), recreation, physical education, or planned exercise, whether at school, at home, or in the neighbourhood (WHO, 2020).

Thus, designing for physical activity extends beyond creating sports infrastructure. It involves creating diverse, stimulating, and inclusive environments that invite people of all ages, abilities, and identities to engage in physical activity in any urban setting.

5.5.1. Physical Inactivity as a Global Pandemic

Obesity and other noncommunicable diseases (NCDs) are among the most critical public health challenges of the 21st century. Globally, over 340 million children and adolescents aged 5–19 were overweight or obese in 2016, with rates continuing to rise in both high- and low-income countries (WHO, 2021). A major driver of this trend is physical inactivity: according to the World Health Organization, 81% of adolescents do not meet the recommended minimum of 60 minutes of moderate- to vigorous-intensity physical activity per day. In 2012, The Lancet declared physical inactivity a new global pandemic due to its increasing public health burden follwed by WHO in 2018 that launched the Global Action Plan on Physical Activity 2018–2030, aiming to reduce physical inactivity by 15% worldwide. Supported by growing scientific evidence, the focus of public health efforts has since shifted from targeting individual behavior alone to adopting systemic approaches that incorporate urban planning, spatial equity, and epidemiological research.

The consequences of inactivity are both direct and far-reaching. In the short term, insufficient movement impairs cardiovascular and metabolic health, weakens the musculoskeletal system, and negatively affects mental well-being and cognitive development. In the long term, sedentary lifestyles established in childhood contribute to sustained patterns of inactivity and increased risk of chronic disease in adulthood. The indirect effects also impact academic performance, social integration, and the socioeconomic burden on families and healthcare systems. Key negative impacts of inactivity in children are summarized in Table 5.5.1.

Table 5.5.1. Negative Health Impacts of Physical Inactivity in Children

Health domain	Negative health impact of inactivity	References
Physical Health	Increased risk of overweight and obesity; reduced cardiovascular fitness; lower bone density	WHO, 2020; WHO, 2018; EU Science Hub, 2020
Motor Development	Delayed development of gross motor skills; poor coordination and balance	WHO, 2020; EU Science Hub, 2020; Janssen & LeBlanc, 2010
Mental Health	Higher risk of anxiety, depression, and mood disorders	WHO, 2018; Biddle & Asare, 2011; EU PA Fiche, 2018

Health domain	Negative health impact of inactivity	References
Cognitive Function	Reduced concentration, memory, and academic performance	WHO, 2020; Singh et al., 2012; EU Science Hub, 2020
Emotional Regulation	Lower stress resilience and emotional self-control	WHO, 2018; Bratman et al., 2019; EU PA Fiche, 2018
Social Well-being	Decreased peer interaction and teamwork skills; increased risk of social exclusion	WHO, 2018; Brussoni et al., 2015; EU Science Hub, 2020
Long-term Health Outcomes	Elevated risk of chronic diseases in adulthood (e.g. diabetes, heart disease, metabolic syndrome)	WHO, 2018; EU Science Hub, 2020; Telama et al., 2005

Recognizing these risks, amongst other relevant urban settings, the WHO emphasizes the critical role of schools in fostering active lifestyles. Through quality physical education, active play, and supportive school environments, children can develop lifelong physical and health literacy. The WHO's Global Action Plan on Physical Activity 2018–2030 highlights the importance of a whole-of-school approach, where daily routines, schoolyard design, and access to recreational opportunities enable all children to engage in regular physical activity and reduce sedentary behaviour.

5.5.2. Studying physical (in)activity in school-related environments

According to WHO and other relevant scientific sources, multiple factors contribute to physical inactivity in urban environments, with the built environment recognized as both a key barrier and enabler of physical activity. From prioritising cars over pedestrians, to a lack of safe and accessible walking infrastructure, inadequate access to green and recreational spaces, and an overall poor quality in terms of safety, lighting, and variety of amenities, the urban environment often discourages movement and contributes to sedentary lifestyles, particularly among children and other vulnerable groups.

Other aspects that discourage physical activity include social and cultural factors (eg. gender norms, age, or cultural and religious expectations limiting movement, especially for girls), economic factors (eg. lack of affordable or free public options for physical activity), and digital and technological factors (eg. increased screen time and sedentary digital engagement across all age groups). In recent decades, exposure to climate and environmental hazards (eg, prolonged heatwaves and UHI effect) has further reduced opportunities for physical activity while increasing health risks. Finally, the weak integration of physical activity as a priority in urban planning, transport, education, and health policy is slowing down the systemic change.

Studying physical activity or inactivity is therefore a complex multidisciplinary process that requires involvement of different perspectives. It spans from epidemiologic study to spatial and environmental analysis involving dimensions such as spatial inequity, climate-related risks, and the characteristics of the built environment. Considering the aim and scope of the research, in this work, the study of physical activity is focused on the analyses of spatial and environmental conditions within and around schools that influence opportunities for physical activity and contribute to physical inactivity among children.

Drawing on international frameworks and the literature review, this section focuses on identifying key environmental determinants and outlining design strategies that promote physical activity across three spatial scales: macro (neighborhood), meso (school interface), and micro (schoolyard and its elements). Furthermore, the following criteria is proposed for the evaluation of the physical (in)activity in relation to school-related environments:

1. **Access and Active mobility** evaluates whether and how children can reach and move through the space. It includes the following notions (WHO, 2018):
   - *Street connectivity and walkability*
   - Proximity to destinations (school, green spaces, public transport)
   - Physical accessibility for all users (age, ability, stroller/wheelchair access)
2. **Safety** assesses the physical and perceived safety of crossings, streets, waiting areas, and public spaces (such as parks, playgrounds, and schoolyards), as well as the quality of lighting and visibility, and the maintenance and cleanliness of these areas (WHO, 2018; Sallis et al., 2016; Faulkner et al., 2010).
3. **Environmental quality** assesses environmental conditions and hazards that influence willingness to move, particularly thermal comfort (shade, ventilation) and contact with nature (presence of green areas for recreation, presence of natural elements along paths, e.g., streets with trees) (Dadvand et al., 2014; Jay et al., 2021; Nieuwenhuijsen, 2020).
4. **Design affordances** focus on the quality and diversity of activity-supportive features. Includes spaces for both active and passive movement, like benches for leaning/stretching, railings for hanging, ledges to sit and observe, or informal corners that allow quiet physical engagement without pressure (Gibson, 1979; Fjørtoft, 2004; Dyment & Bell, 2008).
5. **Social inclusion** examines whether the space supports equitable use and encourages all children to participate. From gender-sensitive layout and age-appropriate activity infrastructure to considering socio-cultural sensitivity (Andersen et al., 2022; Sam & Kouhirostami, 2020; WHO, 2018).

While the objectives of climate resilience (improving thermal comfort and reducing health-related risks) and biotope regeneration (enhancing ecological value) remain relatively consistent across spatial scales, promoting physical activity requires a differentiated approach. In this case, each spatial scale—macro, meso, and micro—holds a distinct role in enabling movement and shaping behavioral patterns.

At the **macro scale**, the emphasis is on active mobility infrastructure and walkability, including safe street networks, crossings, and connectivity to transit and green spaces. This scale is also an opportunity for integrating playful qualities into the urban landscape through interventions such as colourful sidewalks, interactive elements at crossings, or informal sports/play zones in small residual spaces, which can stimulate movement beyond commuting needs.
Furthermore, as noted in the child development section, the presence of walkable, safe pedestrian environments and a well-connected public transport network plays a key role in supporting the autonomy of both younger and older children.

At the **mesoscale**, the focus is on the accessibility and playfulness of buffer zones, drop-off areas, façades, rooftops, and building edges, which can either encourage or limit activity. These spaces hold potential for integrating playable infrastructure and informal activity zones, promoting both passive and active movement of not only children, but as well their caregivers (parents, grandparents) while they wait, or transit between spaces. Furthermore, it is important to mention the indoor school spaces that are widely recognized as important environments for promoting physical activity. However, as they fall outside the scope of this research, which focuses on outdoor and transitional spaces, these aspects will not be further explored.

Lastly, in **micro scale**, the analysis concerns the overall school outdoor space, its topography, spatial configuration, play zones, and affordances for diverse forms of movement and interaction.

5.5.3. Key Determinants and Indicators for active school-related environments

Applying the proposed five criteria to current school-related spaces often reveals an evident lack of diverse, stimulating, and inclusive environments for movement and exploration. Schoolyards dominated by asphalt, fenced sports courts, or repetitive play structures all limit opportunities for children, especially girls, younger age groups, and neurodiverse children, to engage in meaningful physical activity.

At the macro scale, autonomy and walkability/bikeability vary significantly across different cultural and geographical contexts. For example, in Northwest European countries such as the Netherlands and Denmark, walking and cycling to school are the norm across all age groups, supported by safe infrastructure and a culture of active mobility. In contrast, in many Southeast European countries, children are more often accompanied by car, due to safety concerns, low-quality infrastructure, or longer commuting distances.

This contrast highlights the importance of context-sensitive indicators that capture not only the physical conditions but also the cultural and policy environments that influence how—and whether—children are able to move independently and actively in their everyday routines.

At the micro scale, many schoolyards discourage physical activity due to it design features that limit movement, diversity, and inclusion. Common issues include monofunctional design with paved yards with limited and often monothematic equipment (e.g., one large concrete field) that restrict activities types and intensities gender differences. Lack of thermal comfort, especially during warmer months, due to lack of shade, presence of heat-absorbing materials, and lack of quality green areas, not only discourages physical activity but also puts children at risk. While playing, children are often unaware of the heat-related hazards that can lead to heat stress, dehydration, and, in extreme cases, heat stroke.

Gendered or exclusive layouts are wide spread with boys often dominating central open fields, marginalizing girls or children with disabilities (Andersen et al., 2022). Over-regulation or risk-averse design further limits opportunities for exploration, while material monotony further limits sensory exploration. On the other hand, pavements are often inadequate, with hard or uneven surfaces that reduce usability, especially for wheeled movement.
Overall lack of movement loops or routes, such as trails, circuits, or paths, limits dynamic movement.

These barriers often intersect with other forms of spatial inequity, disproportionately affecting girls, younger children, and children with disabilities or neurodivergence. Table 5.5.4. Summarised key determinants limiting physical activity and respective indicators.

Note: Considering the clear overlap with the spatial inequity and climate resilience lenses, the indicators related to walkability, accessibility, or thermal comfort are mentioned as they have a crucial role in promoting physical activity. However, to avoid repetition, in the REACTIVE framework and toolkit, they will be addressed in depth in their respective sections. Instead the design strategies and solutions regarding the physical activity, presented in the next chapter, will focus on assessing the spatial and environmental opportunities for unstructured, spontaneous, and everyday movement within and around school environments.

Table 5.5.3 Physical (In)Activity Determinants and Indicators for School-Related Environments

Physical (in)activity determinant	Criteria	Design Relevance	What to Observe / Measure	References
Safe, accessible infrastructure	Access & Active Mobility	Pedestrian paths, crossings, and bike lanes	Presence and quality of sidewalks, crossings, and cycle lanes near schools; traffic speed	WHO, 2018; Sallis et al., 2016; Frank et al., 2006
Active mobility	Access & Active Mobility	Street hierarchy and priority for cars vs. active mobility	Presence of cycling infrastructure (bike paths, bike parkings)	Frank et al., 2006; Giles-Corti et al., 2016
Connectivity and land use segregation	Access & Active Mobility	Mixed-use development and street network design	Intersection density, connectivity indices, land-use mix	WHO, 2018; Sallis et al., 2016
Rate of active commuting	Access & Active Mobility	Support for walking and biking to school	Proportion of students walking or biking (survey or observational count);	WHO, 2018; Pucher & Buehler, 2012; Faulkner et al., 2010
Access to parks and green spaces	Environmental Comfort	Proximity and accessibility of green public spaces	Green space per child, distance to parks, safe access to play/ recreation areas	WHO Regional Office for Europe, 2016; Dadvand et al., 2014
Urban heat and extreme weather	Environmental Comfort	Shade structures, tree canopy, material choices	Shade coverage, surface temperature, usability during peak heat (pedestrian, paths, entries, waitings areas, play and sport infrastructure)	Jay et al., 2021; WHO, 2018; Nieuwenhuijsen, 2020
Air pollution and traffic emissions	Environmental Comfort	Air quality monitoring and proximity to major roads or polluters	PM2.5/NOK exposure levels near schools or play areas	WHO, 2016; Nieuwenhuijsen, 2020; Vienneau et al., 2017
Flooding and drainage	Environmental Comfort	Stormwater infrastructure and access resilience	Frequency and severity of pathway/entrance/ playground flooding; presence of water retention design elements	WHO, 2018; EPA, 2016; Acuto et al., 2020
Diverse movement affordances	Activity Affordances	Design of elements that support varied movement: jumping, climbing, crawling, balancing, passive use	Presence of logs, mounds, rails, steps, ledges, textured surfaces, informal seating, or interactive elements	Gibson, 1979; Fjørtoft, 2004; Dyment & Bell, 2008
Active opportunities along school edge/ entrances	Activity Affordances	School thresholds and building edges as active zones (e.g. climbing walls, rooftop access)	Presence and usability of building edges, playful fences, façade interaction, rooftop spaces	Arup, 2020; Herrington et al., 2007
Gender sensitive design barriers	Social Inclusion	Spaces dominated by competitive or gendered use discourage girls or non-binary children	Presence of inclusive zones, variety of activity options, gender distribution in space use	Andersen et al., 2022; Sam & Kouhirostami, 2020; WHO, 2018
Cultural and social norms	Social Inclusion	Cultural or religious norms may restrict movement for girls or children in specific communities	Observational or participatory assessment of underrepresented user groups in physical activity areas	WHO, 2018; Murtagh et al., 2015; Garrido et al., 2020

5.5.4. Active design: Strategies for active school-related environments

Active design promotes physical activity through the built environment. Daily movement is essential not only for cardiovascular and musculoskeletal health, but also for brain development, emotional regulation, and academic success. Schoolyards, in particular, offer a unique opportunity to support diverse movement types, ranging from structured play to informal exploration, while addressing inequities in physical activity opportunities related to gender, age, or ability. Overall, design should aim to invite movement without forcing it by providing a variety of supports, surfaces, and affordances that children can use according to their comfort, mood, and developmental stage. Designing for inclusive and playful movement involves creating a landscape of opportunities, rather than simply assigning zones for activity. Universal effective strategies for active school environments include (but are not limited to):

Table 5.5.4.a Key Design Strategies for Promoting Physical Activity in School-Related Environments

Strategy	Activity support	Design Application
1. Diversity	Encourages multiple types of zones (active, social, calm, solo/group) that accommodate diverse activities (sport, informal play, quiet movement)	Avoid single-purpose layouts (e.g., courts designed for football only). Use adaptable, durable materials that support a range of play and movement styles across various age groups.
2. Movement loops and trails	Supports continuous, dynamic movement across space	Design circuits with sensory elements, resting spots, shading, and variable terrain
3. Topographic variety	Encourages climbing, balance, jumping, and exploration	Integrate slopes, mounds, tunnels, and hills adapted for all ages and mobility levels
4. Climbable and modifiable structures	Stimulates gross motor skills and risk-managed exploration	Provide structures of varying height, texture, flexibility, and visibility
5. Affordances for all abilities	Promotes inclusive physical activity for children with different needs	Avoid “special” zones for disability; embed universal design across all areas
6. Inclusive and gender-sensitive layout	Avoids spatial marginalization of girls or less dominant users	Break up dominance of large sports fields; activate edges; provide a range of intensities and modalities
7. Unstructured play opportunities and informal play zones	Supports spontaneous, creative, and socially inclusive physical activity. Encourages casual, self-directed movement and spontaneous sport/play	Provide open-ended zones, natural features (logs, mounds), flexible layouts, movable elements. Include small ball courts, painted ground games, ping-pong tables, etc.
8. Sensory play and stimulation	Supports physical and neurological development, especially in early childhood	Use texture-rich materials, sound features, tactile walls, sensory trails, and natural sensory variation
9. Rest zones and passive activity support	Enables low-intensity movement and comfort while staying active	Include ledges, walls, shaded benches, sitting zones, and quiet corners for swaying, pacing, stretching
10. Visual connectivity and supervision	Enhances perceived safety and encourages exploration	Avoid hidden corners or long dead-ends; maintain clear sightlines across play areas
11. Weather-resilient and seasonal design	Promotes year-round activity regardless of weather conditions	Include shading (trees, pergolas), wind/rain protection, drainage, and durable all-season surfacing
12. Multifunctional public spaces	Increases availability of activity-supportive environments near schools	Make plazas, sidewalks, and small parks adaptable to active uses (jumping, games, circuits)

These strategies support the design of school environments that promote physical activity for all. However, special attention must be given to the social and cultural context, as well as to age-appropriate affordances. Table 5.5.4.b. summarizes Age-Specific Design Strategies.

Table 5.5.4.b. Age-Specific Design Strategies for Physical Activity in School-Related Environments

Age group	Strategy	Activity support	Design application
Early Childhood (3–6 years)	Sensory-rich environments	Supports motor development and sensorimotor integration	Include texture-rich paths, sound features, water play, soft ground materials, and loose parts (e.g., sand, natural elements)
	Low-height, safe challenges	Encourages confidence-building and risk navigation	Provide climbable elements at child-scale, balance beams, small tunnels, and gentle slopes
	Enclosed play areas	Supports autonomy within a safe boundary	Use low fencing or planting to define zones without restricting visibility
Middle Childhood (6–12 years)	Modular and diverse play zones	Supports skill development, group and solo play	Provide multi-use courts, climbing nets, flexible ball areas, and areas for both active and calm play
	Movement circuits and topography	Encourages extended, dynamic play	Design loops with slopes, mounds, variation in materials and terrain
	Opportunities for social play	Stimulates teamwork and communication	Include group games (painted ground games, ping pong), shared swings, and sit-play elements
Adolescents (12+ years)	Autonomy-supportive spaces	Encourages self-directed movement and social gathering	Provide open-ended sport zones, skate areas, informal zones to hang out and move freely
	Youth-specific recreational features	Responds to interests and identity exploration	Include basketball courts, workout stations, parkour zones, and shaded seating for social interaction
	Passive activity and quiet movement	Supports regulation, inclusion, and comfort	Offer benches, ledges, walking loops, and “chill” spaces adjacent to activity areas

Furthermore, the design should incorporate gender-sensitive principles in both spatial layout and activity options, thus avoiding dominant-use zones (e.g., central football fields often occupied by older boys), creating overlapping areas where different forms of play can coexist, and providing opportunities for quiet or low-intensity movement such as swaying, balancing, or walking.

It is important to note that gender differences in physical activity patterns begin to emerge around middle childhood, typically between the ages of 6 and 10, and become more pronounced during early adolescence (ages 10–14). Key general differences are summarised in Table 5.5.4.c.

"Gender differences in physical activity levels start early in childhood and increase with age, with girls being less active than boys in almost all countries."
– WHO Guidelines on Physical Activity and Sedentary Behaviour (2020)

Table 5.5.4.c. Gender-Sensitive Design Strategies for Physical Activity in School-Related Environments

Strategy	Gender balance support	Design application
Distribute activity areas across the space	Prevents dominance by a single group (e.g., older boys in the center)	Break up central sports fields; distribute smaller activity pockets throughout the space
Activate edges and transitions	Engages those who may avoid central or high-intensity zones	Use borders for balance beams, hopscotch, chalk zones, benches for light activity or social games
Design for multiple intensities and preferences	Encourages both high-energy and low-energy activity, matching diverse preferences	Include calm play areas, dancing spots, walking trails, ping-pong tables, and zones for stretching or informal movement
Avoid rigid zoning by gender/stereotype	Supports choice and breaks down role expectations	Do not label areas (e.g., "girls' corner"); design universally appealing, flexible spaces
Create overlapping zones of use	Supports mixed-gender play and social interaction	Combine swing sets, climbing frames, and creative play in the same area, avoiding segmentation
Ensure visibility and safety	Builds confidence, especially among girls and younger children	Design open sightlines, shaded resting spots, and seating close to play areas for inclusive supervision
Engage students in participatory design	Helps ensure diverse voices influence the space	Include both girls and boys in co-design processes to reflect their needs and preferences

Figure 5.5.4 Possil Gym Wall, Glasgow, UK. (© erzstudio)

5.5.5. Final considerations

Designing for movement is not simply about adding equipment; it is about creating school routes, micro-urban spaces, and affordances that create playful and innovative opportunities for bodies to move (Dyment & Bell, 2008; Arup, 2020). Ensuring that every child, regardless of gender, ability, or age, has access to playful and varied movement is fundamental for health and well-being (WHO, 2018; Andersen et al., 2022). Abundant scientific literature provides evidence on multiple benefits of physical activity for:

- **Physical health:** Reduced sedentary time, increased cardiovascular and muscular development (Janssen & LeBlanc, 2010; WHO, 2020)
- **Mental health**: Improved mood, lower anxiety (Biddle & Asare, 2011; WHO, 2018)
- **Social development**: Cooperation, negotiation, and peer bonding (Brussoni et al., 2015; Lester & Russell, 2008)
- **Cognitive function**: Enhanced attention and working memory after physical exertion (Singh et al., 2012; WHO, 2020)

Physical activity is one of the most effective preventive measures against non-communicable diseases (NCDs). However, it is highly influenced by spatial and environmental conditions. Promoting physical activity, therefore, requires the creation of thermally comfortable and green urban environments with dense, safe pedestrian networks and a variety of informal play and sport areas that are inclusive of all ages, genders, and abilities.

Figure 5.5.5 Wonder Wood schoolyard, Denmark. (© VEDA landskap)

Figure 5.6. Schoolyard open to community with diverse programs anmd activities for different users.

5.6. Designing for Spatial Inequity

As seen in the previous chapter, spatial inequity, particularly in terms of accessibility, is a key prerequisite for a healthy and active life in cities. Spatial inequity, in particular, refers to the geographically uneven distribution of resources, services, and environmental quality, resulting in systemic disadvantages for certain populations based on where they live, learn, or play (Gonzalez, 2019; WHO, 2010). In urban contexts, these disparities manifest as differences in access to green spaces, exposure to climate hazards, the quality of infrastructure, and the availability of safe, inclusive, and health-promoting environments (WHO, 2017; UNICEF, 2022; Nieuwenhuijsen et al., 2014).

5.6.1. Spatial Inequity and Health Impacts on Children

From a child-centered perspective, spatial inequity directly undermines children's right to grow, play, and learn in safe, healthy, and stimulating environments. Children's physical, cognitive, and emotional development is strongly influenced by the quality and accessibility of their everyday spaces such as schoolyards, surrounding streets, parks, and routes to school. In inequitable urban contexts, these environments often lack basic affordances for active play, sensory stimulation, rest, or social interaction. Moreover, spatial inequity increases children's exposure to environmental stressors such as urban heat, flooding, and pollution, which can compromise thermoregulation, respiratory health, attention capacity, and psychological well-being (WHO, 2017; UNICEF, 2022).

Studies from various urban contexts have shown that schools in low-income or immigrant-dense areas often lack access to high-quality outdoor spaces. Furthermore, the schoolyards are frequently closed outside teaching hours, limiting access for non-school children and the broader community. Many cities worldwide are addressing this lack of accessibility to both green and quality public spaces by investing in schoolyards as multi-functional, community-based environments, opening them beyond the school day to increase access to green and inclusive public spaces. For example, New York City's "Schoolyards to Playgrounds" program has transformed hundreds of public schoolyards into community parks, accessible during non-school hours, particularly in neighborhoods with limited green space (Trust for Public Land, 2020).

However, physical access alone does not ensure equitable use. Research highlights that girls, children with disabilities, and neurodivergent children often feel excluded from play spaces dominated by competitive sports, hard surfaces, or overstimulating environments. These inequities are further compounded by differential exposure to environmental risks (e.g., heat, air pollution) and unequal opportunities for movement, nature contact, rest, and social connection, all of which are essential for healthy development.

These inequities can further deepen health disparities, reduce opportunities for physical and emotional development, and undermine children's rights to equitable urban environments. Table 5.6.1. synthetizes key health-related impacts of spatial inequities in school-related environments.

Table 5.6.1. Health-Related Impacts of Spatial Inequity in School-Related Environments

Spatial Inequity Factor	Health Impacts	References
Exposure to urban heat (UHI)	Heat stress, dehydration, sleep disturbance, reduced concentration	UNICEF, 2022; Xu et al., 2012
Exposure to air pollution (near roads or industrial zones)	Increased incidence of asthma, reduced lung function, impaired cognitive development	Nieuwenhuijsen et al., 2014; WHO, 2016
Overexposure to noise, visual clutter, or overstimulation	Anxiety, emotional dysregulation, decreased sense of safety and belonging	Evans, 2006; Spencer et al., 2022
Lack of green space and natural environments	Higher stress levels, reduced physical activity, increased risk of obesity and mental health issues	WHO, 2017; Markevych et al., 2017
Unsafe or missing pedestrian and cycling infrastructure	Increased risk of traffic injuries and fatalities, limited independent mobility	Giles-Corti et al., 2016; Rothman et al., 2018
Limited access to walkable, active, or play-supportive spaces	Sedentary lifestyles, reduced cardiovascular fitness, lower motor skill development	Sallis et al., 2016; Janssen & LeBlanc, 2010
Inaccessibility of public or school-related spaces for already vulnerable groups	Social isolation, exclusion from peer interaction and play, compounding of developmental and emotional disadvantage	WHO, 2011; UNICEF, 2012; Spencer et al., 2022

5.6.2. Addressing Spatial Inequity in school-related environments

Spatial inequity is not confined to the immediate schoolyard. It operates across multiple spatial scales, from the micro-scale (e.g., lack of shaded benches or greenery in a yard), to the macro-scale (e.g., poorly connected or unsafe pedestrian routes), and up to the city-scale, where certain neighborhoods (often lower-income or ethnically marginalized) are systematically more exposed to climate-related hazards and lacking quality green and public spaces.

Urban heat island (UHI) mapping and flood risk overlays often reveal that the most vulnerable schools are located in the most disadvantaged urban zones, creating cumulative layers of risk and limiting children's health and wellbeing opportunities. Without targeted interventions, such patterns reinforce intergenerational injustice and spatial reproduction of health inequality. Some cities have begun to address these disparities at the city scale: Barcelona, for instance, has prioritized interventions in schools most exposed to air pollution and heat, explicitly using vulnerability and equity criteria to guide school greening and street transformation programs. Similarly, London is developing climate adaptation strategies for schools citywide, based on UHI mapping and local risk assessments, with the aim of ensuring that no school community is left behind in the face of escalating climate impacts. These examples demonstrate the importance of embedding spatial justice into climate resilience planning and show how city-level approaches can complement neighborhood and site-scale interventions.

Therefore, addressing spatial inequity through school-related environments is not only a matter of environmental justice but of developmental justice. This section addresses the often-overlooked dimension of spatial inequity and accessibility, positioning it as a structural determinant of child health and opportunity. It introduces as well, a city-wide scale to support, in particular, the public administration in evaluating the exposure and vulnerability of schools across the city to climate and environmental hazards. Table 5.6.2. summarizes key scales and respective roles in evaluating spatial inequity.

Table 5.6.2. Key scales for analysing spatial inequity.

Scale	Description	Example topics
Micro	Site-specific (schoolyard/playground)	Shading, surfaces, affordances
Meso	Immediate school surroundings	Street crossings, sidewalks, entrances
Macro	Neighborhood-level	Access to green space, walkability, local UHI
City Scale	Urban system-wide	Distribution of vulnerable schools, climate hazard overlays, funding equity

Based on this understanding, following UrbanCare Methodology, and Jeff Speck's "Walkable City" framework, the researcher proposes five key spatial criteria to assess and address spatial inequity in a comprehensive, child-centered, and climate-responsive way. The criteria includes:

1. **Accessibility & Connectivity** assesses the proximity and physical access to schoolyards, green spaces, and public amenities, as well as the quality and continuity of routes connecting them. Includes walkability, active design, and barrier-free design (Giles-Corti et al., 2016; WHO, 2011; Gehl, 2010).
2. **Safety & Perceived Security** to evaluate the physical and perceived safety of spaces, including protection from traffic, adequate lighting, visibility, and infrastructure that supports independent and safe mobility for all users, especially children (Rothman et al., 2018; Spencer et al., 2022).
3. **Environmental Comfort & Microclimate** to assess thermal and environmental quality, including shade, vegetation, air quality, and overall microclimatic performance. These factors influence usability, exposure to heat and pollution, and comfort during different seasons (WHO, 2017; Xu et al., 2012; Nieuwenhuijsen et al., 2014).
4. **User Comfort & Inclusivity** focuses on the presence and quality of age-appropriate, inclusive infrastructure, such as seating, shelter, play areas, and amenities, that support rest, use, and engagement for diverse groups, including children with disabilities and neurodivergent users (UNICEF, 2012; Evans, 2006; Spencer et al., 2022).
5. **Attractiveness & Identity** addresses the design, cleanliness, aesthetic appeal, and cultural relevance of spaces. Well-maintained, visually engaging, and contextually meaningful environments foster a sense of belonging, identity, and social inclusion (Gehl, 2010; UNICEF, 2012; Spencer et al., 2022).

5.6.3. Key Determinants and Indicators for Spatial Inequity and Accessibility

The five spatial criteria introduced capture the core dimensions through which spatial inequity manifests in school-related environments. Each of the criteria reflects underlying spatial and environmental determinants that influence children's exposure to risk and access to opportunity. To effectively assess, compare, and improve school-related environments, these determinants have been translated into measurable indicators. Table 5.6.3. introduces a structured set of indicators linked to each indicator, enabling the evaluation of spatial quality and equity across various scales and contexts.

Table 5.6.3. Spatial Inequity Determinants and Indicators

Determinant	Criteria	Design Relevance	What to Observe / Measure	References
Uneven access to green/public space	Schoolyard availability and proximity	Enables everyday access to nature and public life	% of schoolyards open after hours; walking distance from homes to nearest green/play space	Trust for Public Land, 2020; Gehl, 2010
Poor path quality and walkability	Pedestrian infrastructure and network coherence	Supports autonomous mobility and access	Surface condition, sidewalk continuity, slope, crossings, path network density	Giles-Corti et al., 2016; WHO, 2011
Disconnected neighborhoods	Connectivity to key destinations	Enables equitable access to schools, play, services, transit	Path links to schools, transit stops, green spaces; presence of physical or social barriers	Handy et al., 2002; Hillier, 2007
Traffic danger and unsafe routes	Street safety and crossings	Critical for independent, safe child mobility	Speed-reduction infrastructure, protected crossings, visibility of approaches	Rothman et al., 2018; Sallis et al., 2016
Perceived unsafety/ exclusion	Visibility and enclosure	Influences comfort and willingness to use space	Sightlines, lighting, blind spots, openness at entries	CPTED; Spencer et al., 2022
Lack of inclusive infrastructure	Rest, play, and usability for all	Supports equitable and dignified use by all users	Availability and accessibility of seating, water, shade, tactile and rest features	Evans, 2006; UNICEF, 2012
Gender and neurodiversity exclusion	Diversity of play affordances	Promotes inclusive engagement and reduces social barriers	Types of play opportunities: non-competitive, sensory, open-ended	Kyttä, 2004; Moore et al., 2010
Unequal exposure to UHI and heat	Thermal regulation and shade access	Protects children from heat stress and promotes safe outdoor use	Tree canopy %, shade coverage, UHI risk overlays	WHO, 2017; Xu et al., 2012
Air pollution exposure	Vegetation buffers and proximity to emissions	Supports respiratory health and cognitive function	Presence of green buffers; distance from traffic-heavy roads	Nieuwenhuijsen et al., 2014
Excessive stormwater runoff	Flood-prone surfaces and lack of infiltration	Increases physical risk and limits post-rain usability	% of permeable vs. sealed surfaces; presence of bioswales or drains	EPA, 2022; WHO, 2017
High ambient noise	Noise from traffic or activity corridors	Affects attention, emotional regulation, and well-being	Measured or perceived noise levels; presence of sound buffers	Evans, 2006; Clark et al., 2012
Degraded or neglected public space	Maintenance and cleanliness	Affects perception of safety, care, and inclusion	Litter, graffiti, damaged surfaces, broken fixtures	Gehl, 2010; Evans, 2006
Lack of cultural relevance and identity	Integration of cultural and place-based elements	Enhances belonging, social memory, and emotional connection	Local markers, signage, murals, culturally relevant design features	UNICEF, 2012; Spencer et al., 2022

5.6.4. Design Strategies for Spatial Inequity and Accessibility

As presented so far, spatial inequity manifests through both unequal exposure and access to safe, inclusive, and health-supportive environments. In school-related settings, spatial inequity includes physical barriers, unequal exposure to climate risks, and the exclusion of certain user groups, in particular girls and children with disabilities.

To respond to these challenges, spatial design must move beyond compliance-based accessibility and actively promote equity, autonomy, and inclusion across all user groups. This means designing environments that are perceptually, socially, and environmentally inclusive, allowing every child to feel safe, confident, and engaged in the use of space.

Design strategies are presented in two categories: universal and targeted. Table 5.6.4.a. summarizes key universal design strategies applicable to all. These strategies address structural aspects of access and usability and are foundational to equitable schoolyard and neighborhood design.

Table 5.6.4. Universal Design Strategies

Strategy	Spatial Inequity / Accessibility support	Design application
Barrier-free design	Ensures inclusive access for all physical abilities	Ramps, curb cuts, wide and even paths, tactile paving, accessible entries
Open school facilities to the community	Expands access to school spaces beyond class time	Allow use of schoolyards, gyms, and courts after hours for community
Safe and connected active routes	Supports daily active commuting and healthy routines	Design direct, well-lit, and tree-shaded paths with safe crossings and bike lanes
Distributed rest and support infrastructure	Reduces fatigue and increases usability across ages	Install benches, water points, shaded areas, and handrails in regular intervals
Clear wayfinding and legibility	Helps all users navigate space confidently	Use signage, maps, color cues, and structured layout

While universal strategies provide the base conditions for accessibility, they must be complemented by targeted design strategies that respond to the differentiated needs of specific user groups. Children of different ages, genders, and neurodevelopmental profiles interact with space in unique ways and face distinct barriers to inclusion, autonomy, and participation. Table 5.6.5.b. outlines design strategies that address the differentiated needs of children based on age, gender, and neurodiversity.

Table 5.6.4.b. Targeted Design Strategies for Inclusive School Environments

Strategy	Spatial Inequity / Accessibility Support	Design Application
Age Inclusive Strategies		
Age-appropriate scale and affordances	Ensures usability and engagement across developmental stages	Provide child-scaled elements (e.g., low benches, small play features); include zones for early years, middle childhood, and adolescents
Autonomy-supportive layout	Enables safe, independent movement and exploration	Design visual loops, clear paths, and safe crossings to support children's mobility and orientation
Social and flexible-use zones	Encourages inclusive use for older children and adolescents	Integrate passive seating, open hardscapes, and adaptable social zones
Gender-Inclusive Strategies		
Non-hierarchical space organization	Reduces dominance of single user groups (e.g., boys/sports)	Avoid mono-functional layouts; distribute active and quiet zones evenly
Gender-sensitive play diversity	Promotes participation of girls and marginalized users	Offer a variety of play types (e.g., cooperative, sensory, imaginative), not only competitive sports
Visibility and openness	Enhances perceived safety and comfort, especially for girls	Avoid hidden corners, ensure open sightlines, lighting, and transparency at thresholds
Neurodiversity-Inclusive Strategies		
Low-stimulation and quiet zones	Supports children with sensory sensitivities or neurodivergence	Integrate calm green spaces, acoustic buffers, or retreat nooks into the layout
Predictable and legible spatial organization	Reduces disorientation and anxiety for neurodivergent children	Use clear transitions between spaces, visual cues, and consistent layout logic
Inclusive play and engagement features	Ensures participation regardless of physical or cognitive ability	Provide sensory play, loose parts, swings with harnesses, ground-level elements, and manipulable features

Figure 5.6.4 Restorative nodes.

5.6.5. Final considerations

Spatial inequity must be assessed across multiple scales, as its priorities and impacts shift according to the context. At the city scale, it is crucial to identify which schools are most exposed to environmental and climate-related hazards, such as urban heat or air pollution. At the macro (neighborhood) scale, the focus shifts toward promoting active mobility and supporting children's autonomy. Here, accessibility goes beyond merely overcoming physical barriers and includes factors such as climate exposure, safety, and environmental quality. Addressing spatial inequity also requires deeper understanding and inclusion of gender, disability, and neurodiversity, not just in physical design but in planning priorities. The issue is less about direct health outcomes and more about enabling equitable access to health-supportive environments for all children.

Thus, integrating spatial inequity from the start ensures that design contributes not only to health and climate resilience but also to social justice, inclusion, and spatial quality for all children.

Figure 5.6.5 Inclusive activities for all.

Figure 6. Wander Wood shoolyard, Denmark.

6. A Systemic, Child-Centered Approach to Schoolyard Design

6.1. Spatial Health implications, Synergies, and Design Priorities

Designing climate-resilient and health-promoting schoolyards is not about choosing one intervention over another; it is about recognizing how and which spatial factors serve multiple functions simultaneously. The five lenses introduced in this section– Child Development, Climate Resilience, Biotope Recovery, Physical Activity, and Spatial Equity are interdependent and must be negotiated and harmonized in each context.

Each lens contributes to shaping children's health and well-being, both directly and indirectly, and must be integrated and balanced in context-sensitive design processes. Table 6.1.a summarizes the primary environmental drivers, direct health effects, and indirect developmental outcomes illustrating how and which environmental and spatial conditions in school-related environments interact with child health, revealing opportunities for holistic design interventions.

Table 6.1.a. Summary: Environmental Lenses and Child Health Impacts

Lens	Primary Environemntal Drivers	Direct Health Impact	Indirect Health and Development Impact
Climate Change	Urban heat, flooding, drought, UV radiation, air pollution	Heat stress, dehydration, skin damage, respiratory problems	Reduced physical activity, impaired attention, unequal access to safe outdoor play
Biotope Loss	Sealed surfaces, monoculture lawns, lack of vegetation and habitat	Lower exposure to beneficial microbes, reduced immune resilience	Limited sensory development, emotional detachment from nature, reduced biodiversity learning
Physical Inactivity	Lack of stimulating, safe, and inclusive play zones	Higher risk of obesity, motor delays, cardiovascular issues	Reduced cognitive development, social isolation, increased sedentary behavior
Spatial Inequity & Accessibility	Uneven green infrastructure, physical and social barriers, lack of inclusive design	Greater exposure to hazards in underserved schools, exclusion from activities	Amplified spatial injustice, lower well-being, limited developmental opportunities

From these relationships, key design priorities emerge:

- Age-appropriate zoning to support sensory, emotional, and cognitive needs.
- Thermal comfort and water-sensitive infrastructure to mitigate environmental hazards.
- Ecological richness and habitat value to enhance biodiversity and support nature contact.
- Inclusive and varied play opportunities to encourage movement and reduce health disparities.
- Universal access and walkability to address spatial injustice and promote safe, active travel.

These priorities serve not only their immediate design goals but often contribute to multiple outcomes. The table 6.1.b illustrates how these lenses interact systemically, with positive (+) and negative (–) influences mapped from source to target.

Table 6.1.b Interactions Between Key Environmental and Developmental Dimensions in Schoolyard Design (SOURCE > TARGET).

SOURCE > TARGET	Climate change	Biotope Loss	Physical Inactivity	Spatial Inequity & Access	Child Development	Health
Climate Change (heat, floods, air quality)	–	– Urban heat & drought stress vegetation	– Heat discourages outdoor play	– Heat islands are worse in low-income areas; children with disabilities are more exposed to heat	– Cognitive fatigue; reduced time for motor development	– Heat-stroke, asthma, dehydration
Biotope Loss	– Vegetation loss reduces shading, raises surface temperatures	–	– Lack of greenery limits outdoor play and sensory diversity	– Underserved areas face reduced biodiversity and ecological fragmentation	– Fewer natural stimuli reduce cognitive and emotional development	– Burden on respiratory system
Physical Inactivity	– Car-centric travel raises emissions	– Less active use weakens stewardship	–	– Poor districts lack safe, accessible spaces for play	– Reduced motor skills and executive function development	– Obesity, cardiovascular disease, anxiety, depression
Spatial Inequity & Access	– Hotspots and flood risks are often in deprived areas	– Deprived areas have fewer trees and green spaces	– Unsafe, disconnected environments limit walking, cycling, and everyday movement	–	– Unequal access to play and learning resources	– Increased exposure to pollution, noise, and urban heat; higher injury risk; limits active travel

6.2. Mapping Co-Benefits and Trade-offs

As illustrated, many design strategies simultaneously support several lenses.
For instance **trees and vegetation** provide shade (climate), reduce heat, pollution, and flood risks (health), provide restorative sensory experiences (health), support biodiversity (biotope), define spaces for diverse movement (activity), and are especially impactful in underserved areas (equity).
Shaded rest zones offer thermal relief (climate), sensory calm (health), inclusive retreat spaces (development), and recovery zones during intense activity.
Topographic mounds can improve microclimate by airflow (climate), stimulate gross motor skills (development), and invite active movement (activity).
Green Infrastructure (e.g., rain gardens) manage runoff (climate) while creating sensory-rich microhabitats (biotope) that support science learning and exploratio (development), and encourage physical exploration (activity).

However, not all strategies and funcrions align perfectly. Some interventions may generate conflicts or unintended exclusions, particularly when one lens dominates the design logic. Examples include:

- **Active use vs. Spatial inclusivity:** Large multipurpose sports fields promote physical activity but often dominate available space, marginalize quieter or imaginative forms of play, and reinforce gendered or age-based spatial hierarchies.
- **Structured play vs. Ecological sensitivity:** Highly structured or intensive-use areas can conflict with ecological goals, limiting habitat quality and reducing biodiversity.
- **Greening vs. Surveillance:** Dense vegetation improves microclimate and ecological value but may reduce visibility and perceived safety if not designed with passive surveillance principles.
- **Developmental affordances vs. Institutional regulation:** Natural features like loose rocks, logs, and varied topography support sensory engagement and motor development, but often face institutional resistance due to safety and liability concerns.
- **Cooling features vs. Maintenance burden:** Water elements and other passive cooling systems offer thermal relief and sensory richness but require sustained maintenance and careful risk management.
- **Durability vs. Sensory engagement:** Hard, vandal-resistant materials enhance longevity but often lack the tactile and interactive qualities important for inclusive and developmental environments.

To move from five analytical lenses to an operational toolkit, all lens-specific strategies were first mapped and then compared side-by-side. Table 6.2 captures the outcome of this synthesis: each row represents a strategy family and columns report co-benefit tags, typical synergies, and typical trade-offs/risks observed in real school-related environments. This matrix was used both to prioritize strategies with multi-lens benefits and to anticipate conflicts (e.g., maintenance burden, accessibility constraints, overheating, or inequitable use). The highest-performing strategies form the final toolkit strategy set.

Table 6.2 Co-benefit Strategy Matrix: Each row is one strategy family. Columns show co-benefit tags, plus typical synergies and typical trade-offs/risks. Legend (co-benefit tags): CD = Child Development | CL = Climate Resilience | BIO = Biotope | PA = Physical Activity | EQ = Spatial Equity

STRATEGY	CD	CL	BIO	PA	EQ	Synergies	Trade-offs
1. Shade as a spatial system	●	●	●	●	●	CL-CD (comfort + safety), CL-PA (more active time), CL-BIO (canopy cooling)	Too much shade can reduce winter sun/play usability; design seasonal/ variable shade
2. Cool–permeable ground strategy	●	●	●	●	●	CL-BIO (infiltration + cooling), CL-PA (heat-safe movement), EQ-PA (accessible surfaces)	High-albedo glare or slippery permeables; balance SRI/albedo + tactile safety
3. Water-sensitive design (blue–green infrastructure)	●	●	●	●	●	CL-BIO (runoff + habitat), CD-BIO (learning + nature contact)	Safety/maintenance concerns; design safe edges, overflow, and stewardship

STRATEGY	CD	CL	BIO	PA	EQ	Synergies	Trade-offs
4. Soil regeneration as infrastructure	●	●	●	○	●	BIO-CL (durable planting + cooling), BIO-CD (microbial/nature exposure)	Soil zones get compacted fast; use no-compaction buffers + clear paths
5. Ecological layering (ground–shrub–tree)	●	●	●	○	●	BIO-CL (evapotranspiration + shade), CD-BIO (sensory ecology)	Visibility/safety concerns if too dense; keep clear sightlines + "porous" edges
6. Microhabitats + pollinator support	●	○	●	●	●	BIO-CD (exploration + stewardship), BIO-EQ (nature access for all)	allergies;
7. Nature-play + loose parts	●	○	●	●	●	CD-PA (motor + imagination), CD-BIO (nature contact)	Safety/maintenance debates; use risk-benefit logic + replenishment routines
8. Topographic variety + microclimate form	●	●	●	●	●	PA-CL (cool movement routes), BIO-CD (microhabitats + exploration)	Accessibility if only "stairs + mounds"; ensure parallel accessible gradients
9. Movement loops + micro-trails	●	●	○	●	●	PA-EQ (inclusive daily activity), PA-CL (shade/water nodes extend use)	Can conflict with quiet/rest zones; manage via zoning + buffers
10. Distributed multi-use activity pockets	●	○	○	●	●	PA-EQ (girls/non-dominant users), CD-PA (varied intensities)	Oversplitting can reduce team sport; keep one flexible core + many edges
11. Risk–benefit challenge gradient	●	○	○	●	●	CD-PA (competence + movement), EQ-CD (inclusive autonomy)	Over-risking or over-sanitizing; use graduated heights + surfacing
12. Quiet/restorative micro-spaces	●	●	●	●	●	CD-EQ (dignity + regulation), CL-PA (rest enables sustained activity)	If hidden, they reduce safety; design semi-sheltered, visible refuges
13. Social space diversity (group / small / solo)	●	○	○	●	●	CD-EQ (belonging), PA-EQ (inclusive participation)	Too many seating areas can "freeze" activity; balance with active edges
14. Neuroinclusive gradients + sensory cues	●	○	○	○	●	CD-EQ (orientation + autonomy)	Over-signage/visual clutter; keep clear, minimal cues
15. Universal access + dignity by default	●	○	○	●	●	EQ-PA (participation), EQ-CD (autonomy)	"Accessible route" becomes the only good route; integrate access everywhere
16. Wayfinding + legibility	●	○	○	●	●	EQ-CD (confidence), PA-EQ (safe independent movement)	Over-control can reduce adventure; combine legibility + exploration pockets
17. Visibility-based safety + passive surveillance	●	○	○	●	●	EQ-PA (perceived safety increases activity), EQ-CD (comfort)	Too exposed can remove refuge; design visible privacy (screened, not hidden)
18. Edge buffering + exposure reduction	●	●	●	●	●	CL-CD (health protection), EQ-CL (protect most exposed users)	If buffer becomes "no-go strip"; turn it into productive edge (path + planting)
19. Traffic calming + safe crossings ("last 200 m")	●	●	●	●	●	PA-EQ (active travel), CL-EQ (heat exposure reduction)	Conflicts with car access/parking politics; needs policy + design package
20. Shaded rest + hydration nodes	●	●	○	●	●	CL-EQ (protect sensitive users), PA-CL (sustain outdoor use)	Concentration of amenities can create inequity; distribute them deliberately
21. Weather-resilient year-round use	●	●	○	●	●	CL-PA (activity continuity), CL-EQ (access in all conditions)	Over-hardening can reduce ecology; pair with BIO measures
22. Outdoor learning niches + participatory expression	●	○	●	●	●	CD-BIO (learning through nature), EQ-CD (belonging)	Vandalism risk; reduce through ownership + robust detailing
23. Edible / interactive planting	●	○	●	●	●	BIO-CD (stewardship), PA-CD (active engagement)	Maintenance burden; plan roles, irrigation, seasonal logic
24. Open school facilities + shared access	●	●	●	●	●	EQ-BIO (nature access), PA-EQ (activity opportunities)	Wear/maintenance & governance; requires clear rules + stewardship plan
25. Distributed resource equity	●	●	○	●	●	EQ-PA (equal participation), EQ-CL (heat safety)	Budget constraints; treat as minimum performance rule
26. Age-scaled affordance distribution	●	○	○	●	●	CD-PA (progression), EQ-CD (inclusion across ages)	Segregation risk; use overlapping bands not isolated "age islands"
27. Zoning by intensity + gradients (micro-scale core move)	●	●	●	●	●	The "container" that makes all strategies coexist	If too rigid it becomes control; design gradients + visual connection

6.3. Systemic approach to transformation of school-related environments

The thesis frames schoolyard as a multi-scalar, multifunctional space that intersects children's everyday lives, health determinants, and climate and ecological dynamics. Moving beyond single-purpose or aesthetic redesigns, the five introduced design lenses provide a systemic framework for guiding resilient, inclusive, and health-promoting schoolyard transformations.

At the core of this framework lies a **child-centered interpretation of spatial quality**, where health is not treated as a fixed outcome, but as a condition continuously shaped by:

- The child's developmental stage and sensory-cognitive needs
- Exposure to environmental stressors like heat and ecological degradation
- Opportunities for safe, diverse, and inclusive movement
- Fair distribution of quality spaces across populations

In alignment with Jan Gehl's principle **"first life, then spaces, then buildings,"** this child-centered approach demands that schoolyards be planned around children first. Public space should be co-created to reflect local needs, culture, everyday use, and long-term resilience.

In this context, the five lenses– Child Development, Climate Resilience, Biotope Restoration, Physical Activity, and Spatial Equity, provide a robust structure for both spatial analysis and intervention. Their integration has revealed important insights:

- **Health is not an isolated theme**, but a synthesis of environmental quality, social inclusion, and developmental opportunity.
- Many design strategies provide **co-benefits across lenses** and should be prioritized for their systemic impact.
- Some interventions present **trade-offs** that require careful negotiation through inclusive design and adaptive governance.

From this, **three core principles** emerge:

1. **Prioritize Multi-Benefit Interventions:** Emphasize strategies (e.g., vegetation, flexible play zones, rain gardens) that simultaneously address climate, health, equity, and development.
2. **Balance Trade-Offs Through Inclusive Design:** Use participatory processes and adaptive management to navigate tensions between safety, ecology, and inclusivity.
3. **Embed Health and Development as Spatial Outcomes:** Recognize that physical environments shape children's cognitive, emotional, and physical trajectories.

These principles underpin the REACTIVE Framework and Toolkit which include:

- A multi-scalar audit tool to assess risks and opportunities
- A catalogue of design strategies linked to specific lenses and co-benefits
- A flexible framework and set of indicators for planning, implementation, and evaluation

By adopting a systemic, child-centered lens, schoolyards can become catalytic environments: public spaces that embed care, climate resilience, and inclusive development into the everyday experience of urban life.

Closing remarks

If schoolyards are to become drivers of urban climate resilience and child well-being, they must be seen not as static infrastructure, but as dynamic, adaptive systems embedded within wider spatial, social, and ecological contexts. Their transformation involves far more than physical redesign: it requires shifts in governance, maintenance culture, educational programming, and urban policy.

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PART III -

Best Practices

This section explores best practices for schoolyard transformation. Each case study demonstrates how design strategies respond to local risks while unlocking opportunities for healthier, more inclusive learning environments. The comparative analysis emphasizes the diversity of spatial solutions, governance models, and implementation pathways adopted across Europe, showcasing schoolyards as living laboratories for integrated urban transformation.

7. Best practices analysis

7.1. Introduction

Across the world, diverse actors, including municipalities, schools, research institutions, and non-profit organizations, have initiated transformative projects and policies to address the interlinked challenges of climate change, health, and educational quality in school environments.

Building on the first two parts of the thesis, which explore the theoretical context and introduce the analytical framework, **Part III examines a selection of real-world best practices in schoolyard transformation.** These practical case examples serve to address the second core research question by illustrating how integrated design strategies are applied in diverse international contexts.

RQ2: What can current schoolyard transformation practices teach us about designing for health and climate resilience? This part takes a comparative case study approach to investigate:

- What trends and priorities are shaping schoolyard redesign today?
- What methodologies are used to integrate health and climate goals?
- What are the main enablers (e.g. policies, partnerships, co-design) and barriers (e.g. funding, institutional inertia, regulatory constraints) that affect implementation?
- Which concrete design strategies and solutions have proven effective, scalable, or adaptable?

Rather than showcasing only "success stories," this section also aims to investigate barriers, contradictions, and limitations. By learning from both the strengths and shortcomings of existing projects, it becomes possible to outline realistic, context-sensitive pathways for future transformations, ones that are ambitious yet grounded in the everyday complexities of school systems, urban governance, and community life.

The chapter presents a curated selection of best practices that illustrate a wide range of efforts, highlighting the diversity of initiatives and approaches over the last 40 years. Best practices collected vary from schoolyard transformation projects to subsidy schemes, research projects, and design toolkits. Together, these examples serve both as proof of concept and as a catalogue of strategies to support future interventions. While the global overview of best practices highlights the growing attention given to schoolyard transformation, especially in the past decade, the analysis focuses more closely on the **European context, with particular emphasis on the Mediterranean region**.

The specific objectives of the best practices analysis are:

- **To identify and compare the key challenges and objectives addressed** in different geographical, climatic, and cultural settings, in order to better understand shared priorities and divergent needs.
- **To examine the methods and processes used** in the best practices, identifying effective approaches that can contribute to a transferable methodology for future projects.
- **To extract key insights and recurring strategies** that can inform the development of a replicable, systemic approach for transforming schoolyards into climate-resilient, health-promoting, and active environments.

7.2. Methodology, Templates, and Indicators for Best Practice Analysis

The collection and analysis of best practices was carried out through a mixed-method research approach to answer the **RQ2: What can current schoolyard transformation practices teach us about designing for health and climate resilience?**

Examples were identified via scientific literature, European and international projects, and through targeted web-based exploration of schoolyard transformation projects, municipal initiatives, and programmes. The aim was to collect a diverse set of case studies that reflect different geographical contexts, climate challenges, and institutional approaches. Best practices collected and presented date to 1990s, and although these practices might be outdated, they have a particular value in terms of showcasing: 1) the importance of transforming the concrete schoolyards into green environments, 2) role of schoolayrds within neighboirhood as community resource, and 3) the shift in framing the schoolyard role in wider climate resilience challenge.

7.2.1 Analysis templates and indicators

To systematically compare and extract transferable insights from a wide range of best practices, a structured analysis template was drafted through an iterative research process. Initial versions were informed by the literature review on climate change, health, well-being, child development, and educational equity, which helped define a set of core challenges and outcome domains. As the analysis progressed, the templates were refined to integrate newly emerging themes and reflect the multidimensional nature of the cases.

The template structure was designed to assess if and how each best practice addressed core issues identified in the literature review including the five thematic lenses. The template is organized into five main indicator categories, each containing multiple sub-indicators aligned with the core lenses of the research:

- Basic information and Context (eg. Location, Climate Zone, Initiators and Stakeholders, etc.)
- Key Challenges (climatic, health-related, social/educational) and Objectives
- Methodology, Process, and Solutions andStrategies
- Outcomes, Outputs, and Policy Integration
- Barriers, Lessons, and Innovation Potential
- Sources and references

Considering the diversity of collected best practices, ranging from built interventions to policy tools and research initiatives, the orignal template was adapted to best support a coherent and comparative analysis across all case types. While the overall structure remained consistent, the application of the template was modified to reflect the nature of the initiative:

- For research projects, the emphasis was shifted toward scope, research framing, findings, and transferability potential rather than physical interventions.
- For policy and funding initiatives, more focus was placed on support mechanisms, systemic alignment, and outreach strategies.

The following Table 7.2 presents the full analysis template used for transformation-focused best practices.

Table 7.2.1. Best Practices Analysis Template for Transformation-Focused Best Practice Analysis

Category	Purpose	Guiding qeustions
Basic Information and Context	**Provide core background details to locate the best practice in space, time, and institutional setting.**	
Location	Anchor the project geographically	Where was the initiative implemented? (City, country)
Climate Zone	Contextualize environmental challenges and solutions	What Köppen-Geiger classification? How does the climate influence design needs?
Year	Track temporal evolution and relevance	When did it start? Is it ongoing, concluded, or scaled?
Type of Best Practice	Understand the nature of the intervention	Is it a built transformation, a research study, a funding tool, a policy framework, or a knowledge/resource hub?
N. of Schoolyards Transformed	Assess scale and reach	How many schoolyards were affected directly?
Initiators and Stakeholders	Clarify who led and who was involved	Who initiated the project? What actors were engaged (e.g., government, school, NGO, community, research)?
Short description	-	
Key Challenges and Objectives	**Define the environmental, social, and health challenges the practice aims to address, and outline its primary goals.**	
Climate Change-related Challenges	Identify environmental issues addressed	Heat Stress; Stormwater Management; Droughts; Biotope Loss; Air quality; Climate Adaptation Awareness
Health and Developmental Challenges	Explore human-centered physical, emotional, and cognitive issues	Physical inactivity; Mental health and stress; Overall well-being; Lack of access to nature; Cognitive and learning development (e.g., attention, memory, experiential learning)
Educational Challenges	-	Educational limitations (lack of outdoor learning spaces, limited curricular integration)
Social Challenges	Highlight societal and structural challenges affecting equity and access	Spatial inequity (variability in schoolyard quality across districts; Community engagement and use (schoolyards not shared or co-owned by the neighborhood)
Key Objectives	Highlight main goals	What were the project's declared or implicit aims (e.g., improve education, mitigate heat, foster equity)?
Methodology, Process, Solutions & Strategies	**Focuses on the approach, tools, and implementation pathways used to deliver the intervention.**	
Methodology and Approach	Unpack the process logic	What planning and engagement methods were used? Was it co-designed, top-down, participatory, expert-driven, iterative?
Design and Implementation Strategy	Understand delivery mechanisms	Was it a pilot project followed by scaling? Implemented in phases? Was tactical urbanism or prototyping used?
Solutions & Strategies Adopted	Detail spatial, material, and programmatic solutions	What specific strategies were implemented (e.g., depaving, tree planting, water management, play structures, curriculum integration)?
Outcomes, Outputs, and Policy Integration	**Capture results, tangible products, and connections to broader planning or institutional frameworks.**	
Results	Show outcomes and impacts	What changed physically, socially, and environmentally? Can include informal feedback, evaluation studies, or observed outcomes.
Outputs	Capture tangible deliverables	Were there toolkits, policies, educational programs, maps, guidelines, or other replicable outputs?
Connection to Urban Policy & Planning	Assess systemic integration	Was it embedded in climate, education, health, or spatial planning frameworks? Were urban policies influenced or created to support the project?
Barriers, Lessons, and Innovation Potential	**A critical reflection section based on the author's synthesis of project documentation and observed practices.**	
Key Lessons	Summarize what worked well and what others can learn from	What are the most critical takeaways from this case? What made it effective? What design or policy insights does it offer?
Key Barriers	Identify obstacles that slowed or limited implementation	What challenges were encountered (technical, financial, political, social)? How were they addressed—or not?
Innovation	Highlight what is new or original	What creative, novel, or unique approaches did this practice introduce in terms of design, process, or governance?
Transferability Potential	Assess how applicable it is to other contexts	Can this be replicated elsewhere? What conditions (approach, governance, funding, climate, culture, tools) enable or limit its transferability?
Sources and References	Includes citations, URLs, or project documentation used to compile the analysis.	

8. Schoolyard initiatives over the past 40 years

Based on the analysis of best practices from 1990 to 2025, it is fair to say that the United States has been a front runner in schoolyard transformation projects, with initiatives emerging in the 1990s (Fig. 7). Initially focused on greening and educational goals, U.S. practices were largely community-led and driven by hands-on experience. These early projects emphasized greening, environmental education, and play as central elements of the schoolyard transformations.

In contrast, Europe began institutionalised schoolyard transformation more recently, within the past 10-15 years, as a result of broader policy agendas related to climate adaptation, sustainability, and urban regeneration.

Today, both trajectories are converging toward multifunctional, climate-adaptive, and inclusive schoolyard design, with Europe currently experiencing a rapid expansion and mainstreaming of such initiatives.

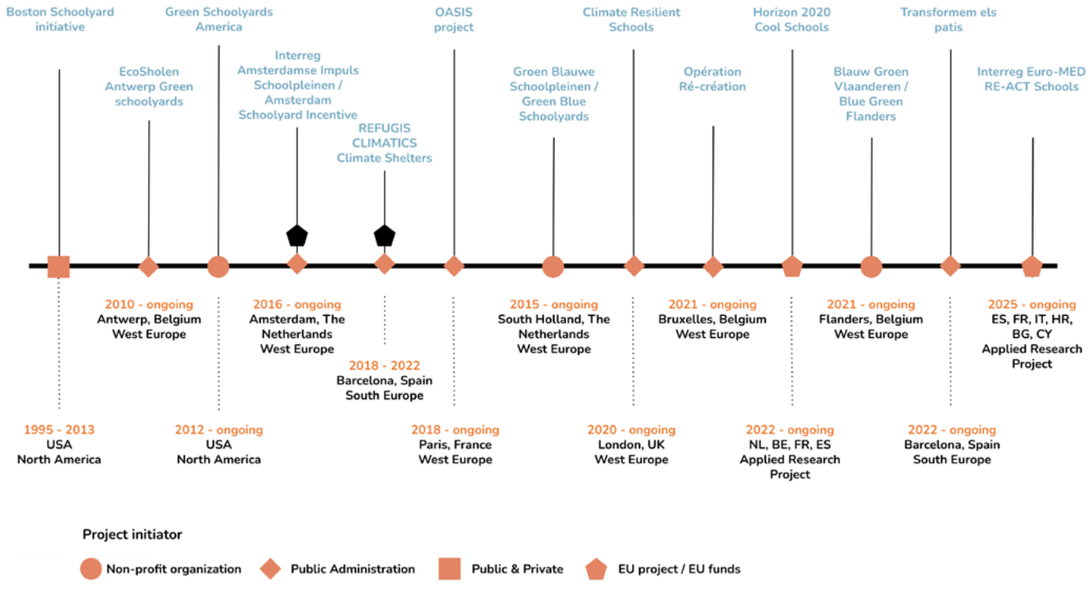


Fig 8. Best practices timeline, including main worldwide projects and initiatives since 1995.

8.1. The United States as an Early Leader

In the 1990s, the U.S. saw a significant rise in schoolyard greening initiatives, largely driven by environmental education movements, public health concerns, and grassroots community efforts. Programs like Boston Schoolyard Initiative (1993-2013), Edible Schoolyard Project (started by Alice Waters in 1995), Learning Landscapes in Denver, and NYC Schoolyard Programme (1996-present) became models for transforming asphalt-dominated schoolyards into multifunctional green spaces that promote learning, environmental stewardship, and community use (Dyment & Bell, 2008; Moore & Wong, 1997).

These projects were often funded and initiated through public-private partnerships, philanthropic contributions, and community-based organizations, rather than national policy. The U.S. approach emphasized:

- Outdoor learning environments
- Environmental education
- Community engagement
- Addressing environmental inequities (e.g., greening low-income urban schoolyards)

A noteworthy example in the United States is the scaling up of New York City's schoolyard greening efforts into the Community Schoolyards™ program, which since 2021 has expanded nationally with support from organizations like Trust for Public Land. This initiative reflects a growing commitment to climate adaptation, green infrastructure, and resilience funding, reimagining schoolyards as vital public assets for both education and community well-being.

Furthermore, platforms such as the Children & Nature Network and Green Schoolyards America play a key role in promoting the sustainable transformation of school environments, offering toolkits, advocacy resources, and capacity-building programs. Their work has also contributed to the policy landscape, most notably with the introduction of the Living Schoolyards Act (S-1538) to the U.S. Senate by Senator Martin Heinrich (D-N.M.). The proposed legislation aims to direct federal resources toward upgrading school grounds into nature-based, climate-resilient learning environments, supporting shaded play, gardening, and outdoor education while helping communities adapt to extreme weather.

8.1.1. Boston Schoolyard Initiative

GENERAL INFORMATION & CONTEXT

Location	Boston, MA, USA
Climate Zone	Dfa (Humid continental, hot summer)
Year(s)	1995-2013
Type	Transformation project
N. of schools	88
School level	Elementary and Middle Schools
Project Initiators	Public-private partnership (City of Boston, Boston Public Schools, and the Boston Schoolyard Funders Collaborative)

SHORT DESCRIPTION

Between 1995 and 2013, the Boston Schoolyard Initiative (BSI) transformed Boston's schoolyards from barren asphalt lots into dynamic centers for recreation, learning and community life. BSI was a public-private partnership among the City of Boston, Boston Public Schools, and the Boston Schoolyard Funders Collaborative. Through a participatory process the initiative engaged children, families, community members and teachers into the creation of outdoor spaces for increased physical activity and creative new approaches to using the schoolyard for teaching and learning.

OBJECTIVES

- Revitalise neglected schoolyards
- Create attractive public spaces for recreation, education and civic activity
- Support meaningful and innovative educational use of schoolyards
- Cultivate significant public participation, including many community-based organisations, in both the design and stewardship of the schoolyards.

PROCESS

Participatory co-design	Strong community involvement
Pilot / prototyping	Not applied
Phased implementation	City-wide scaling
Monitoring & feedback	Limited evaluation

8.1.1. Boston Schoolyard Initiative

CHALLENGES ADDRESSED

Climate-related hazards	
Environmental stressors	
Health & Development	
Education	
Spatial Justice	

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

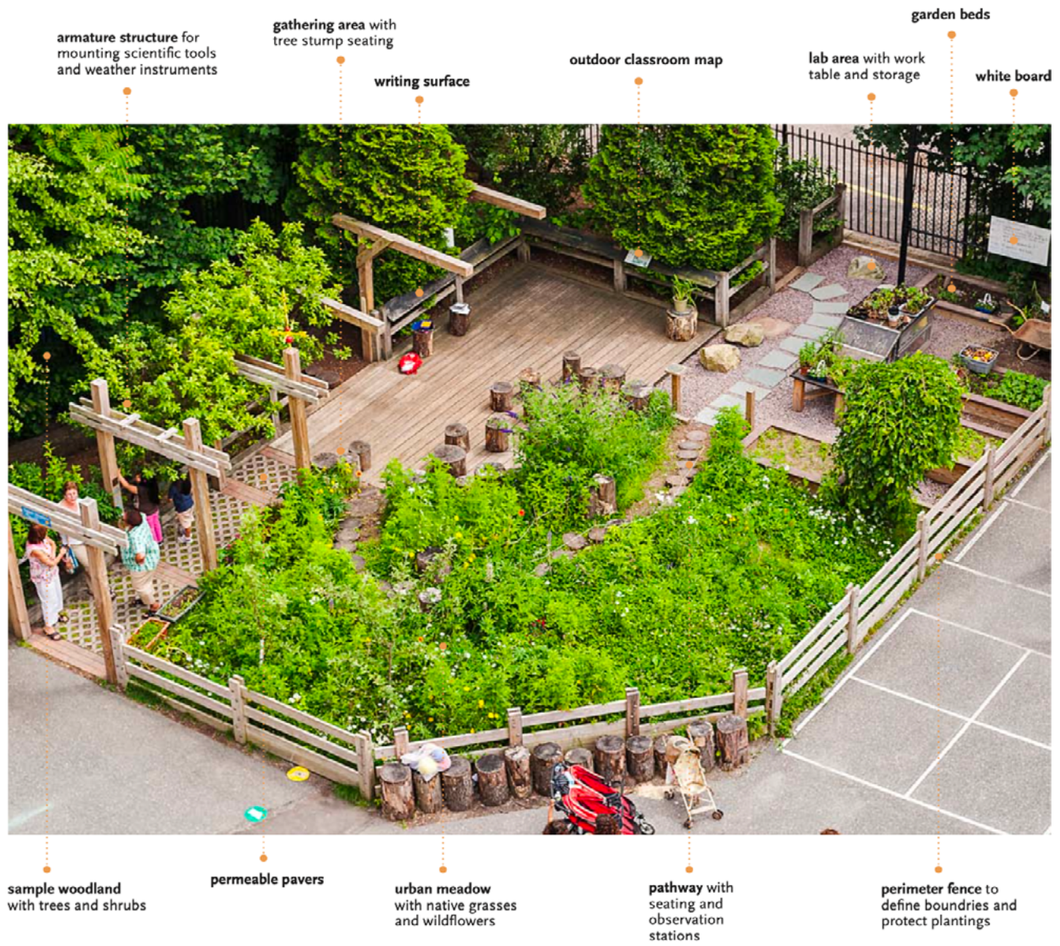
- Schoolyard Design Guide
- Outdoor Classroom Design Guide
- Surveys and Checklists

INSTITUTIONAL EMBEDDING

yes/**no**

8.1.1. *Boston Schoolyard Initiative*

LESSONS LEARNED	ø **Early community engagement** was essential for long-term use, maintenance, and ownership of the transformed spaces
KEY BARRIERS	ø **Maintenance** responsibilities remained a challenge, with initial funding not always matched by long-term stewardship plans or adequate municipal support. ø The initiative required strong cross-sector collaboration, which was not always easy to coordinate across education, planning, and park departments.
INNOVATION	ø Boston was a pioneer in **linking curriculum integration with schoolyard design**, making outdoor learning a formal component of educational reform. ø Its focus on **teacher empowerment and professional development** through environmental education is still relatively unique among schoolyard greening programs.
TRANSFER POTENTIAL	ø Key enablers for replication include: a clear institutional lead (like Boston Public Schools), multi-year funding commitment, and investment in teacher training alongside physical upgrades.
REFERENCES	http://www.schoolyards.org/



8.1.2. New York Schoolyards Programme and Community Schoolyards™ Programme

GENERAL INFORMATION & CONTEXT

Location	New York, NY, USA
Climate Zone	Dfa (Humid continental, hot summer)
Year(s)	1996-ongoing
Type	Transformation project
N. of schools	over 214 NYC schoolyards
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Public-private partnership (Non-profit Organization The Trust for Public Land (TPL), NYC Parks, NYC Department of Education, local schools

SHORT DESCRIPTION

The NYC Schoolyards Program was launched in 1996 by the Trust for Public Land (TPL) to transform underused, paved schoolyards in New York City into green, community-accessible playgrounds. The early projects focused on improving access to nature, promoting equity, encouraging outdoor play, and applying participatory community design. In 2007, the initiative expanded citywide under Mayor Bloomberg's PlaNYC, launching the "*Schoolyards to Playgrounds*" program in partnership with NYC Parks, the Department of Education, and the School Construction Authority. In recent years (2020–2025), TPL has scaled up these efforts and launched a national framework called the *Community Schoolyards™ program*, with an expanded focus on climate adaptation, green infrastructure, and federal climate resilience funding.

OBJECTIVES

- Replace asphalt with green, multifunctional schoolyards that serve educational and community purposes
- Integrate environmental education, hands-on gardening, and cooking lessons alongside enhanced outdoor play
- Ensure equitable access by focusing on underserved neighborhoods

PROCESS

Participatory co-design	Strong community involvement
Pilot / prototyping	Not applied
Phased implementation	City-wide scaling
Monitoring & feedback	Limited evaluation

8.1.2. New York Schoolyards Programme and Community Schoolyards™ Programme

CHALLENGES ADDRESSED

Climate-related hazards	
Environmental stressors	
Health & Development	
Education	
Spatial Justice	

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Community SchoolyardsTM projects
- Living Schoolyard Guidelines (together with Green Schoolyards America and Oakland Schools Unified District)

INSTITUTIONAL EMBEDDING

yes/no

NYC Schoolyards Program has been embedded in urban policy and planning through PlaNYC since 2007.

8.1.2. New York Schoolyards Programme and Community Schoolyards™ Programme

LESSONS LEARNED

- **Unstructured play is vital**: Child-led, unstructured activities (e.g. socializing, informal games) increased dramatically—from 24–41% to 52–64%—suggesting that flexible environments support natural engagement .
- **Access is essential**: Reliable public opening hours are crucial. At P.S. 242, inconsistent gate access limited community use—highlighting the need for dependable scheduling and stewardship
- **Community partnerships matter**: Projects with active community organizations saw stronger community engagement. Selecting the right partner is key.

KEY BARRIERS

- **Maintenance challenges**: Maintaining grounds upkeep and ensuring consistent access require ongoing effort.
- **Safety and access concerns:** Locked gates and neighborhood safety issues sometimes blocked public usage—even when spaces were improved
- **Institutional limitations**, including school bureaucracy and inconsistent custodial practices (e.g., gate locking), hindered program goals.
- **Community buy-in variability**: Some community partners failed to fully embrace public activation. The need for well-matched, mission-aligned partners is a recurring observation.

INNOVATION

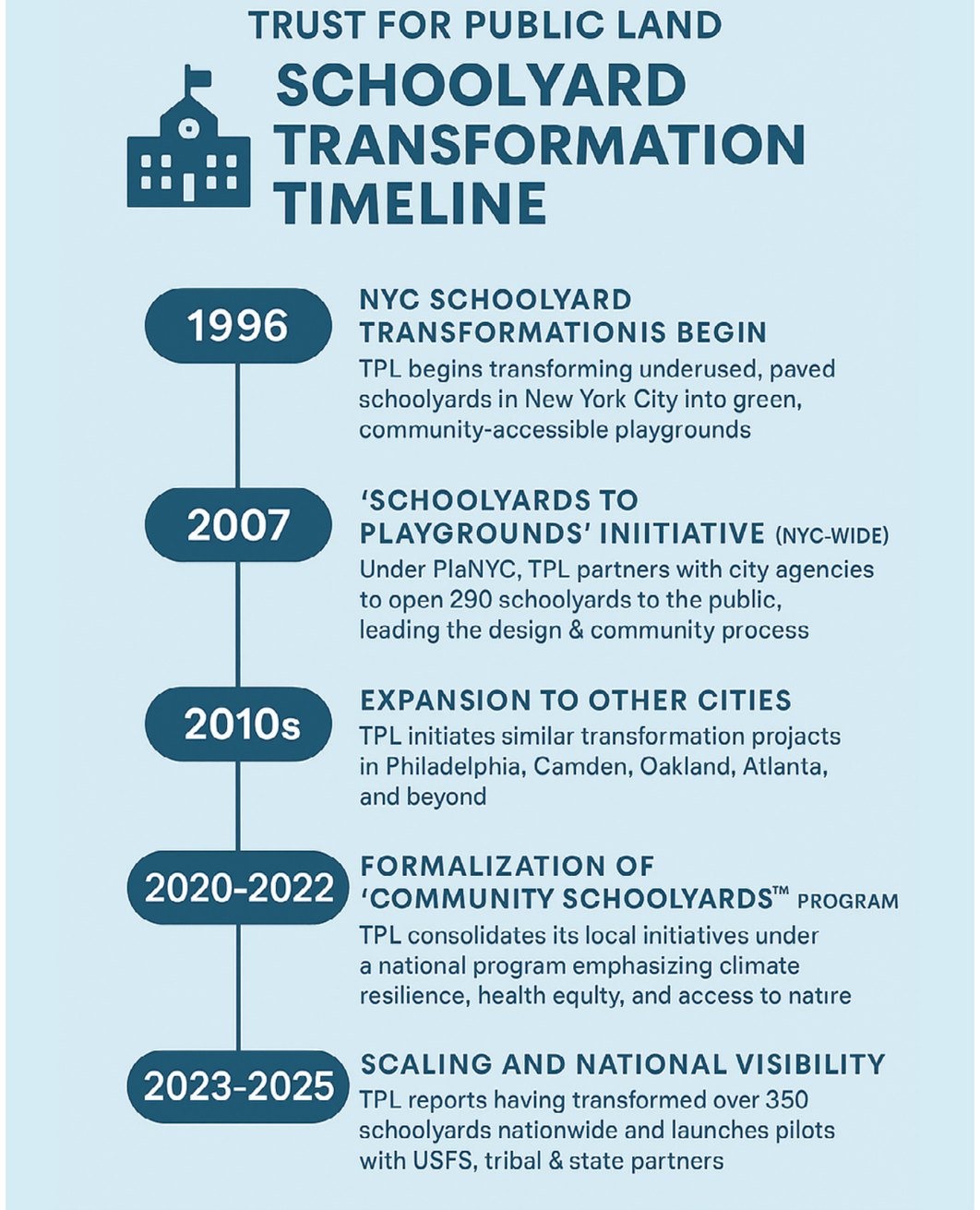
- **Multifunctional landscape**: Blending structured sports, natural surface zones, seating, and turf supported diverse activities—including educational use

TRANSFER POTENTIAL

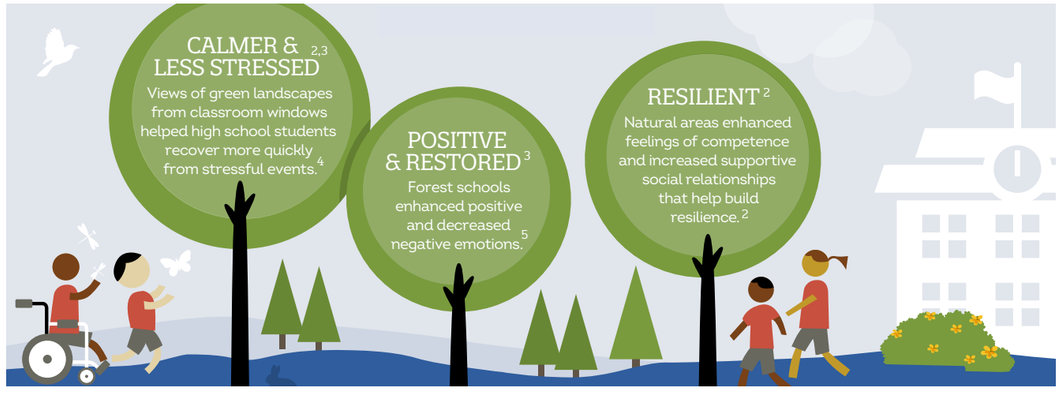
- High

REFERENCES

https://www.tpl.org/our-work/new-york-city-playgrounds
https://www.tpl.org/our-work?_categories=schoolyards
https://www.nycgovparks.org/greening/schoolyards
https://www.tpl.org/wp-content/uploads/2023/05/TPL_Community-Schoolyard-projects_digital.pdf



8.1.3. *Children Nature Network*



GENERAL INFORMATION & CONTEXT

Location	USA
Year(s)	2006 - present
Type	Resource hub, Research, Policy Advocacy
Scope of support:	Educators, school districts, community practitioners globally
Level of operations:	International
N. of schools	No direct implementation; supports local actors via tools/ grants
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Nonprofit organization, supported by philanthropic, academic, and governmental partnerships.

SHORT DESCRIPTION

C&NN is a nonprofit that collects and shares research, tools, and inspiration to support community, educational, and greening schoolyards and outdoor learning environments.

OBJECTIVES

- Promote child health and learning,
- Promote equity,
- Promote climate resilience through nature-rich schoolyards

PROCESS

Participatory co-design	Strong community involvement
Pilot / prototyping	Not applied
Phased implementation	City-wide scaling
Monitoring & feedback	Limited evaluation

8.1.3. *Children Nature Network*

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Digests on health, equity, pedagogy; greening galleries; mini-grants; community networks

INSTITUTIONAL EMBEDDING

yes/no
C&NN has influenced the inclusion of green schoolyards in child-friendly city and climate resilience conversations globally

8.1.3. Children Nature Network

LESSONS LEARNED
- Evidence helps build cross-sector support; multi-benefits strengthen case

KEY BARRIERS
- Gender-equity focus in play access

INNOVATION
- Gender-equity focus in play access

TRANSFER POTENTIAL
- Very high—resources are broadly applicable; adaptable tools for diverse educational and planning contexts

REFERENCES

https://www.childrenandnature.org/

SUPPORTING RESEARCH

[1]www.cdc.gov/physicalactivity/data/facts.htm [2]Dyment & Bell (2008). Grounds for movement: Green school grounds as sites for promoting physical activity. *Health Educ Res* , 23(6), 952-962. [3]Barton et al. (2015). The effect of playground- and nature-based playtime interventions on physical activity and self-esteem in UK school children. *Int J Environ Health Res* , 25(2), 196-206. [4]Dyment et al. (2009). The relationship between school ground design and intensity of physical activity. *Child Geogr* , 7(3), 261-276. [5]Brink et al. (2010). Influence of schoolyard renovations on children's physical activity: The Learning Landscapes Program. *Am J Public Health* , 100(9), 1672-1678. [6]Mårtensson et al. (2014). The role of greenery for physical activity play at school grounds. *Urban For Urban Gree* , 13(1), 103-113. [7]Pagels et al. (2014). A repeated measurement study investigating the impact of school outdoor environment upon physical activity across ages and seasons in Swedish second, fifth and eighth graders. *BMC Public Health* , 14(1), 803.

ADDITIONAL RESEARCH USED FOR THIS INFOGRAPHIC AVAILABLE AT research.childrenandnature.org

C&NN recognizes that not all studies support causal statements.

8.1.4. Green Schoolyards America

GENERAL INFORMATION & CONTEXT

Location	USA (national, based in California)
Climate Zone	-
Year(s)	2012 - present
Type	Resource hub, Research, Policy Advocacy
N. of schools	Indirect support through research, frameworks, advocacy
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Nonprofit-led initiative with school districts, public health departments, and design professionals.

SHORT DESCRIPTION

Green Schoolyards America (early 2010s–present) is a California-based national nonprofit that drives systems change to turn asphalt school grounds into "living schoolyards." It combines research + GIS (tree-canopy equity mapping), policy/advocacy, and capacity-building (resource libraries, technical assistance) to help districts and agencies scale shade, outdoor learning, and green infrastructure. It launched the Schoolyard Forest System approach, centering equity and climate resilience.

OBJECTIVES

- Promote outdoor learning and ecological awareness
- Support systemic transformation
- Integrate climate and health resilience into education planning

PROCESS

- **Research** — Statewide school tree-canopy quantification
- **Participatory co-design** — Institutionalize child participation
- **Policy / Advocacy** — Supports/advances state/federal policy to unlock funding and remove regulatory barriers.
- **Support/technical assistance** — Limited evaluation

8.1.4. Green Schoolyards America

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
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- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- California Schoolyard Forest System
- Tree Canopy Equity Assessment incl. Interactive GIS mapping tool
- Living Schoolyards Act template

INSTITUTIONAL EMBEDDING

- (**yes**/no)
- Aims to integrate green schoolyards into education, climate, and health policies at the state/district level

8.1.4. *Green Schoolyards America*

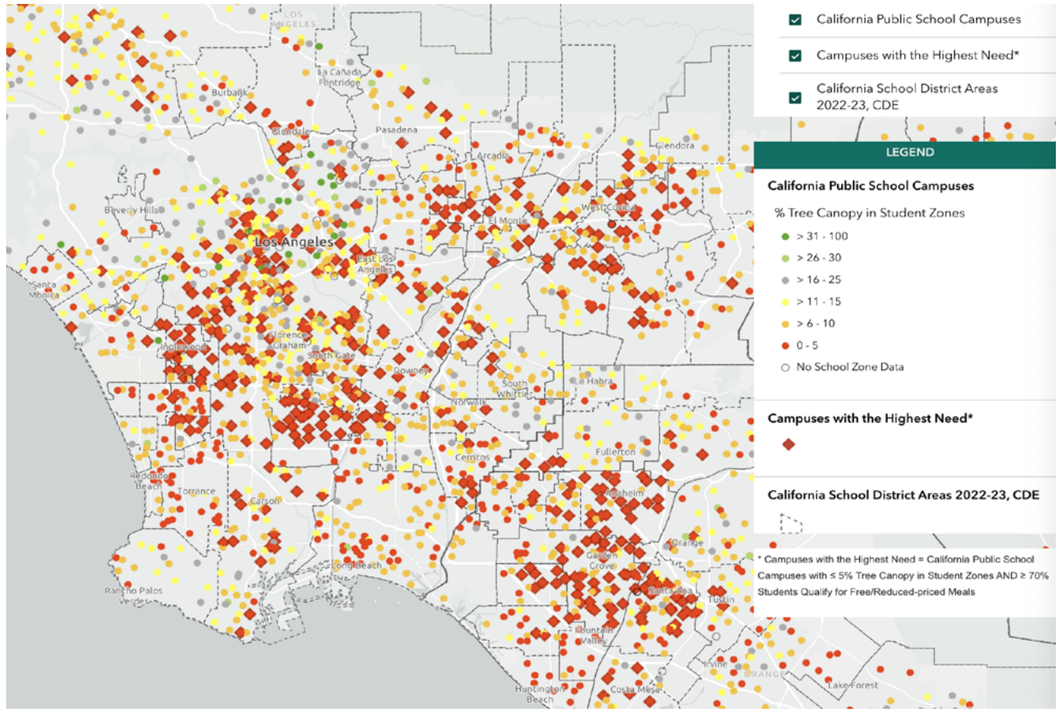
LESSONS LEARNED
- Data and mapping are essential to drive investment and policy attention
- Co-design must include children; scaling research flags that kids are often absent from planning conversations

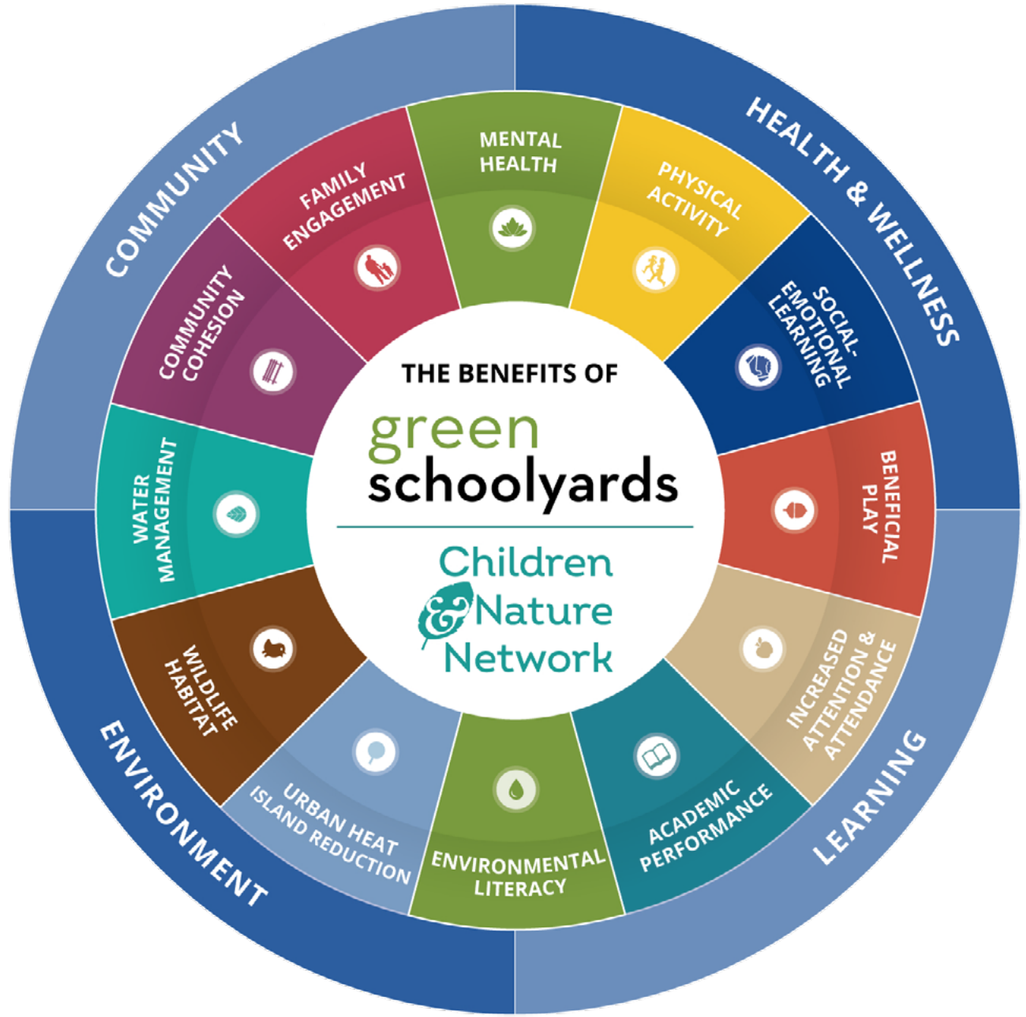
KEY BARRIERS
- Limited funding and political inertia;
- Implementation lag behind policy intent

INNOVATION
- GIS-based Tree canopy equity modeling;
- Systemic district-level approach aiming to **institutionalize green schoolyard transformation as a standard practice**.
- Policy-first framework

TRANSFER POTENTIAL
- High – policy models, GIS tools, and schoolyard frameworks are adaptable

REFERENCES https://www.greenschoolyards.org/





8.1.5. Toyota Evergreen Learning Grounds program

GENERAL INFORMATION & CONTEXT

Location	Canada
Climate Zone	-
Year(s)	1993 - 2010 (extended into later years)
Type	Transformation project
N. of schools	Approx. 3.000 schoolyards
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Public-private partnership (Toyota Canada & Evergreen)

SHORT DESCRIPTION

Toyota Evergreen Learning Grounds (Evergreen's program from 1993; Toyota partnership from 2000) funded and coached schools to turn barren asphalt into nature-rich "living labs" and outdoor classrooms. Through small grants, design support, teacher workshops, and community stewardship, it helped green ~3,000 Canadian school grounds and reach 1M+ children—adding trees, gardens, habitat and natural play while embedding curriculum outdoors.

OBJECTIVES

- Improve **ecological quality**
- Promote **hands-on environmental education**
- Improve **community and student engagement**

PROCESS

Funding scheme	Small grant ~CAD 3,500
Co-design with experts	Planing and design support
Build with community	Implementation through community
Capacity-building learning outcomes	Teacher workshops + resource library/how-to guides

8.1.5. Toyota Evergreen Learning Grounds program

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Small grants for implementation
- Landscape design guidance, teacher workshops, and resources
- A national Native Plant Database and educational materials

INSTITUTIONAL EMBEDDING

(yes/**no**)

8.1.5. *Toyota Evergreen Learning Grounds program*

LESSONS LEARNED

- Small-scale, community-led greening can result in **widespread ecological and educational benefits**.
- Teacher training and participatory design are essential for sustained impact.

KEY BARRIERS

- Limited scale due to small grant size and resource constraints
- Maintenance issues and need for continuing community involvement

INNOVATION

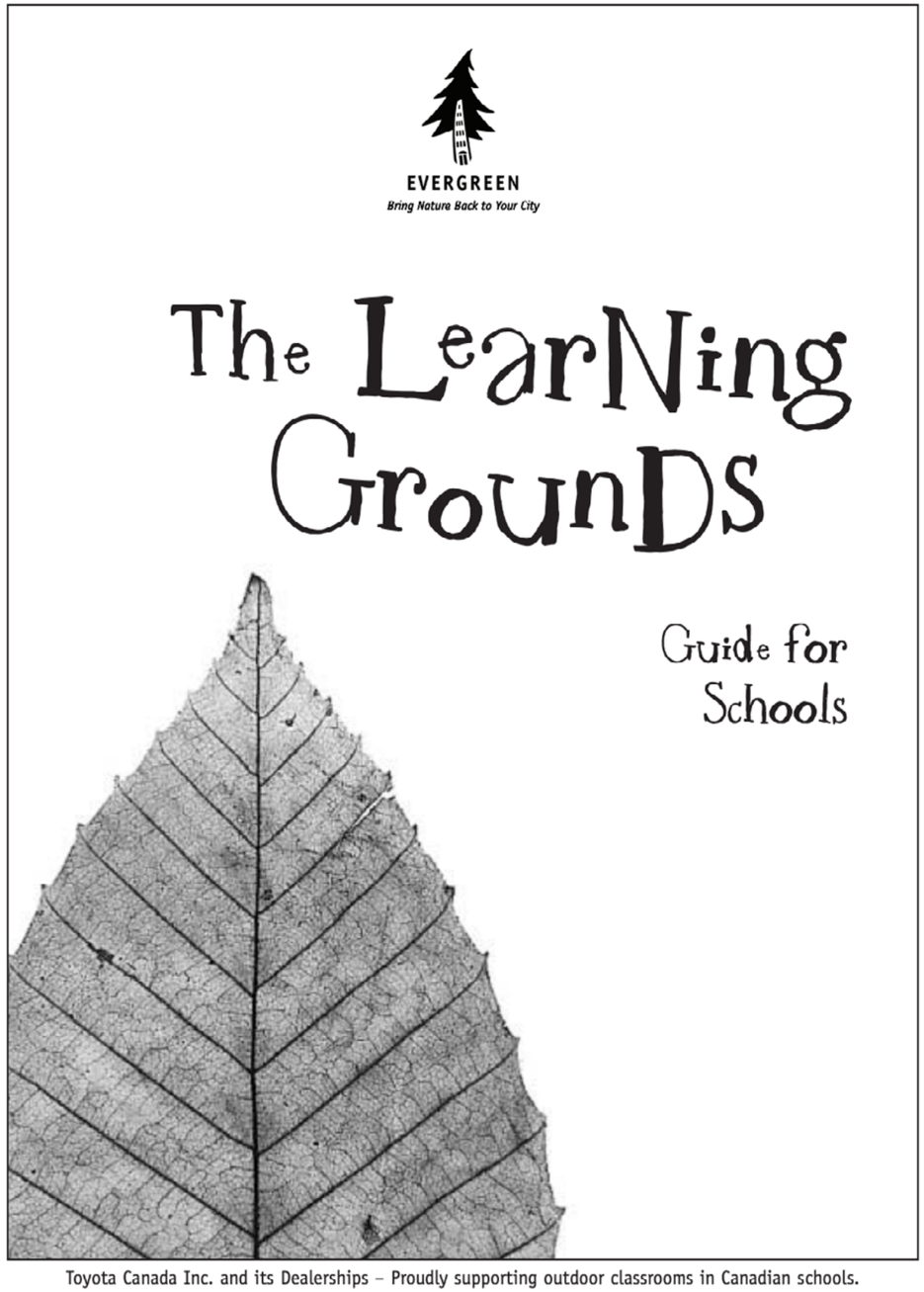
- One of the **first national-scale schoolyard greening efforts**, combining corporate support and grassroots engagement
- Introduced **nature-rich outdoor classrooms** integrated with hands-on learning in Canada

TRANSFER POTENTIAL

- **High** for grassroots models using small grants, corporate-nonprofit partnerships, and community engagement
- Less scalable for systemic transformation due to **lack of embedded policy frameworks**; success depends on local initiative and sustained resources

REFERENCES

https://dnr.maryland.gov/wildlife/Documents/Learning-Grounds-Guide-for-Schools.pdf
https://media.toyota.ca/en/releases/2009/schools-encourage-students-to-get-dirty-studying-nature.html?utm



8.1.6. Evergreen's Climate Ready Schools

GENERAL INFORMATION & CONTEXT

Location	Milton, Ontario, Canada
Climate Zone	Cfb (Temperate oceanic)
Year(s)	2020–2022 (concept launched in 2020; school completed October 2022)
Type	Transformation project
N. of schools	1 pilot (Irma Coulson Public School)
School level	Kindergarten - Grade 8
Project Initiators	Public-private partnership (Evergreen; Halton District School Board; landscape architect Birgit Teichmann; community & students; funders: Balsam Foundation, Intact, others)

SHORT DESCRIPTION

Canada's first Climate Ready School, developed by Evergreen in partnership with the Halton District School Board and landscape architects, transformed Irma Coulson Public School into a climate-resilient, nature-rich learning and community space with co-created design guided by the **Sponge Schoolyard** strategy .

OBJECTIVES

- Improve climate resilience
- Encourage child development
- Increase outdoor learning opportunities
- Create multi functional spaces for students and local community
- Involve students and the local community in the process

PROCESS

Participatory co-design	Strong community involvement
Pilot / prototyping	Not applied
Phased implementation	City-wide scaling
Monitoring & feedback	Limited evaluation

8.1.6. Evergreen's Climate Ready Schools

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Pilot resources and communication materials shared via Evergreen's Resource Hub

INSTITUTIONAL EMBEDDING (**yes/no**)

- Was it embedded in climate, education, health, or spatial planning frameworks? Were urban policies influenced or created to support the project?

8.1.6. *Evergreen's Climate Ready Schools*

LESSONS LEARNED	ø Multi-solving design combines play, learning, health, biodiversity, and climate resilience.
KEY BARRIERS	ø Scale and cost: high resource requirement for one-to-one pilot projects. ø Maintenance: requires sustained community/board stewardship for complex green infrastructure .
INNOVATION	ø Sponge Schoolyard approach: first full-scale application of Berlin-inspired stormwater design in Canadian schoolyards ø Multi-solving integration: combining climate adaptation, pedagogy, and social activation in one comprehensive design model
TRANSFER POTENTIAL	ø **High** for school districts with resources and climate mandates – offers a well-documented blueprint. ø **Moderate** for smaller or under-resourced districts unless simplified or modular models are used.
REFERENCES	https://www.evergreen.ca/projects/canadas-first-climate-ready-school/ https://www.evergreen.ca/impacts/climate-ready-schools/#:~:text=How%20school%20grounds%20are%20designed,both%20children%20and%20their%20communities https://www.childrenandnature.org/resources/canada-evergreen-climate-ready-schools/

8.2. More Recent Attention in Europe

In Europe, while some earlier initiatives existed (e.g., Scandinavian outdoor classrooms and nature schools from the 1960s–1980s), the broad recognition of schoolyards as key spaces for environmental, educational, and health interventions gained significant momentum mainly in the last two decades (Malone & Tranter, 2003; Woolley & Lowe, 2013).

The recent shift of focus in schoolyard transformation initiatives, reflects both changing societal priorities and the influence of global and regional frameworks such as the 2015 Paris Agreement, the EU Strategy on Adaptation to Climate Change (European Commission, 2021), and the growing uptake of the UNICEF Child-Friendly Cities Initiative. These agendas have framed schoolyards not only as environments for children, but also as multifunctional public spaces that can serve broader goals of climate resilience, social inclusion, and public health.

In the past 10–15 years, Europe best practices showcase:

- **A rise in national and municipal policies that explicitly prioritize schoolyard transformation as part of urban resilience.** For example, Barcelona's "Refiugis Climatics" program, which aims to convert all schoolyards into inclusive, climate-adaptive spaces; or Paris's "OASIS" project, which is transforming 770 courtyards into urban cooling shelters by 2050.
- **A shift toward integrated design approaches that combine climate adaptation** (e.g., heat mitigation, stormwater management), biodiversity enhancement, and social equity, targeting schools in vulnerable neighborhoods or areas with limited green access (e.g., OASIS, Refugis Climàtics, AIS Amsterdam).
- **An emphasis on opening schoolyards to the wider public outside school hours,** in response to urban densification, green space scarcity, and a push for environmental justice. This model can be seen in Paris, Brussels, Barcelona, and Amsterdam, where schoolyards are reframed as part of the city's public space system.
- **Stronger institutional alignment with climate adaptation policies,** especially after the Paris Agreement and EU Urban Agenda, positioning schoolyards as climate shelters: multifunctional spaces designed to mitigate heat, reduce flood risk, and provide safe outdoor environments for children and the broader community during extreme weather events (European Commission, 2021; Climate-ADAPT, 2023).

8.2.1. EcoScholen – Antwerp Green Schoolyards

GENERAL INFORMATION & CONTEXT

Location	Antwerp, Belgium
Climate Zone	Cfb (Temperate oceanic: mild summers/winters)
Year(s)	2010–present
Type	**Transformation project**, research project, **subsidy scheme, resource hub**
N. of schools	19
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	City of Antwerp (EcoHuis, Climate Plan 2020–2030), schools, parents, teachers, students, NGOs

SHORT DESCRIPTION

Antwerp's green schoolyard program began in 2010 with a pilot school supported by the local Flemish government. The success of the pilot project prompted the creation of new policies and widespread support to continue greening school grounds throughout the rest of Belgium. Today, the City of Antwerp supports greening school grounds through financial and technical assistance. Schools can apply to receive funding from the Climate Fund for climate-resilient interventions in school grounds, such as de-paving, adding green stormwater infrastructure, and planting vegetation. Greening school grounds is also included as a strategy in the city's climate plan for 2020-2030.

OBJECTIVES

- Greening schoolyards as part of climate adaptation strategy
- Creating child-friendly community play spaces
- Fostering environmental awareness and equitable access to green infrastructure

PROCESS

Intake	Clarify why, what goals (climate-aware vs climate-robust)
Candidacy + selection	Schools receive 3 years of intensive coaching
Subsidy	Subsidies ~ €30 000 per school and coaching from EcoHuis
Evaluation	Progress is reviewed annuallyfor 3 years

8.2.1. EcoScholen – Antwerp Green Schoolyards

CHALLENGES ADDRESSED

Climate-related hazards

Environmental stressors

Health & Development

Education

Spatial Justice

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Subsidy and coaching scheme (€30 k/school)
- Teacher training & resources
- Promotional material (posters, events, public narratives)

INSTITUTIONAL EMBEDDING

(**yes**/no)

- The EcoScholen program is embedded in Antwerp's Climate Plan 2020–2030 and coordinated through EcoHuis. It supports city-wide green infrastructure goals and is implemented at the district level.

8.2.1. EcoScholen – Antwerp Green Schoolyards

LESSONS LEARNED

- **Clear funding and support mechanisms** (including co-financing and guidance) enable schools to implement green schoolyard projects with greater confidence and consistency.
- **Practical resources and visual guides** help schools understand and replicate effective design approaches.

KEY BARRIERS

- Challenges include maintaining responsibilities and ensuring equitable distribution, as well as embedding these practices in the long term.

INNOVATION

- The EcoSchool model and subsidy offer two different trajectories for schools: one focused on climate awareness and the other on climate robustness. A climate-aware school takes measures to reduce its CO2 impact and works on energy, sustainable mobility, sustainable food, or a healthy indoor climate, for example. The school also works on raising awareness and promoting behavioural change around climate issues among pupils, teachers, and the environment. A climate-robust school works on implementing climate adaptation measures, such as installing a natural playground, a green roof, and/or a facade garden. The school also focuses on involvement, support, and awareness among students, teachers, and their environment.
- Integration with Antwerp Climate Plan embeds the initiative into city-wide policy

TRANSFER POTENTIAL

- High transferability across European school systems with similar climate and governance conditions.

REFERENCES

https://www.antwerpenvoorklimaat.be/advies-begeleiding/eco-scholen-klimaattraject
https://www.antwerpenvoorklimaat.be/inspiratie-speelnatuur
https://www.antwerpenvoorklimaat.be/verhalen-ecoscholen-laerhof
https://www.childrenandnature.org/resources/belgium-city-of-antwerp-ecohouse/

8.2.2. Blauw Groen Vlaanderen - Blue Green Flanders

GENERAL INFORMATION & CONTEXT

Location	Flemish Brabant, Belgium
Climate Zone	Cfb (Temperate oceanic: no dry season, mild summers/ winters)
Year(s)	2017 - present
Type	Resource Hub, Subsidy Scheme
N. of schools	Over 100 schools supported; Provides tools, subsidies, and guidance directly enabling schoolyard transformations.
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Provincie Vlaams-Brabant, Blauw Groen Vlaanderen, local schools, regional education and environment departments, experts and design professionals

SHORT DESCRIPTION

Blauw Groen Vlaanderen is a regional initiative in Flanders supporting the transformation of schoolyards into blue-green, nature-based, multifunctional play and learning environments. The program offers funding, design tools, and technical guidance, promoting high-quality and resilient outdoor spaces.

OBJECTIVES

- Support the development of climate-adaptive, biodiverse, and educational outdoor environments in schools;
- Promote child well-being;
- Promote sustainable water and nature management through design.

PROCESS

Initiate	Create a team (teachers, pupils, parents, neighbours/other)
Fund	Identify external partners and check subsidy options
Design	Use the site's design "rules of thumb" and 8 principles
Implement	Plan > build > activate + manage

8.2.2. Blauw Groen Vlaanderen - Blue Green Flanders

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
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- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Online design tools and catalogues;
- 8 principles for quality schoolyards;
- Inspirational cases;
- Downloadable planning kits;
- Up to €25,000 subsidies.

INSTITUTIONAL EMBEDDING

(**yes**/no)

- Connected to regional and local climate strategies; promotes alignment with nature-based solutions and educational planning policies in Flanders.

8.2.2. *Blauw Groen Vlaanderen - Blue Green Flanders*

LESSONS LEARNED

- A **clear, principle-based quality framework** (the 8 Design Principles) helps ensure consistency and replicability across schoolyard transformation projects while allowing for local adaptation.
- The initiative demonstrates the value of **publicly accessible online tools** (e.g. project maps, self-assessment forms) in promoting transparency, participation, and knowledge exchange among stakeholders.

KEY BARRIERS

- Challenges include maintenance responsibilities and ensuring equity in distribution, and embedding practices long-term.

INNOVATION

- Combining climate, education, and design toolkits as one package

TRANSFER POTENTIAL

- High transferability across European school systems with similar climate and governance conditions.

REFERENCES https://blauwgroenvlaanderen.be/scholen/

FILTER BY

THEME

- Preventing flooding
- Water reuse
- Limiting drought
- Limiting heat
- Strengthening biodiversity
- To play
- To learn

TREES

DEHARDENING

NATURAL SUN PROTECTION

INFILTRATION BASIN AND DITCH

AMPHITHEATER/OUTDOOR CLASSROOM

WILLOW TUNNEL/HUT

VARIED PLANTING

BLUE-GREEN ROOF

UNDERGROUND WATER STORAGE

PERMEABLE (SEMI)PAVING

GUTTERS AND WATERWAYS

DISCONNECTING RAINWATER DRAINAGE

HEIGHT DIFFERENCES AND SUNKEN AREAS

WADI

SEAT EDGES

8.2.3. Groenblauwe Schoolpleinen - Blue Green Schoolyards

GENERAL INFORMATION & CONTEXT

Location	South Holland Province, The Netherlands
Climate Zone	Cfb (Temperate oceanic: mild summers/winters)
Year(s)	2018 - present
Type	Resource Hub, Subsidy Scheme, Policy tool
N. of schools	Over 250 schools supported; Provides tools, subsidies, and guidance directly enabling schoolyard transformations.
School level	Kindergarten, Elementary, Middle, and High School.
Project Initiators	Provincial governments (e.g. Gelderland), IVN Natuureducatie, schools.

SHORT DESCRIPTION

Groenblauwe Schoolpleinen is a Zuid-Holland (NL) initiative that helps schools convert hard, grey yards into blue–green, climate-adaptive play and learning spaces. It provides a step-by-step process, examples/webinars, and a subsidy scheme that can cover design, construction, and early maintenance. Run by Province of Zuid-Holland with water authority Delfland, it links school grounds to heat, flooding and nature goals.

OBJECTIVES

- Increase nature exposure,
- Manage rainwater,
- Combat heat

PROCESS

Initiate	Strong community involvement
Fund	Not applied
Design	City-wide scaling
Implement	Limited evaluation

8.2.3. Groenblauwe Schoolpleinen - Blue Green Schoolyards

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Online design tools and catalogues;
- 8 principles for quality schoolyards;
- Inspirational cases;
- Downloadable planning kits;
- Up to €25,000 subsidies.

INSTITUTIONAL EMBEDDING

yes/no

Connected to regional and local climate strategies; promotes alignment with Nature-based solutions and educational planning policies in South Holland.

8.2.3. *Groenblauwe Schoolpleinen - Blue Green Schoolyards*

LESSONS LEARNED

- **Having a predefined set of design criteria or quality guidelines** (like checklists, spatial standards, or performance expectations) simplifies and accelerates the implementation process across many schools

KEY BARRIERS

- Funding is finite and competitive
- Maintenance capacity is the bottleneck: without a clear beheer/ownership plan, green-blue elements deteriorate fast (watering, pruning, repairs).
- Administrative + coordination takes time and expertise (permitting, procurement)
- Space/program conflicts: keeping enough hard surface for circulation/sports while adding infiltration + biodiversity requires careful design trade-offs.

INNOVATION

- Institutionalized subsidy model with predefined nature-based criteria
- Replicable delivery: a clear public stappenplan, cases, and webinars make it easier for many schools to start and standardise quality.

TRANSFER POTENTIAL

- High – structured criteria + funding is replicable in similar governance contexts

REFERENCES https://www.groenblauweschoolpleinen.nl/

8.2.4. Amsterdamse Impuls Schoolpleinen (AIS) - Amsterdam Schoolyard Incentive

GENERAL INFORMATION & CONTEXT

Location	Amsterdam, The Netherlands
Climate Zone	Cfb (Temperate oceanic: mild summers/winters)
Year(s)	2016–present (Pilot 2016–18, municipal scheme since 2019)
Type	Transformation project, Subsidy Scheme, Policy tool,
N. of schools	54 as of end 2022 (24 schoolyards in the pilot phase 2016-2018; 30 schoolyards via subsidy scheme 2019-2022); Priority is often given to schools in vulnerable neighborhoods or heat-stressed areas.
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	City of Amsterdam; Project Management Bureau Amsterdam (PMB); independent Advisory Committee; school boards; district committees; landscape and water management experts

SHORT DESCRIPTION

Amsterdam's "Amsterdamse Impuls Schoolpleinen" (AIS) became an annual municipal subsidy in 2019, building on the Interreg PERFECT pilot (2016). It funds the upgrade of paved schoolyards into green, inclusive, climate-responsive play and learning spaces with public access beyond school hours. The pilot greened 24 yards (+19,000 m²), adding nature play and rainwater measures. Schools can receive up to €70,000 plus PMB expert support (landscape, climate, education). Prioritised in the 2022–2026 Coalition Agreement.

OBJECTIVES

- Make schoolyards as accessible as possible outside of regular school hours
- Create more playgrounds in the city,
- Provide school children with a green space to play in.
- Focus on low-income areas of the city and improved community integration.

PROCESS

Call + eligibility check	School board applies for a one-off subsidy (max €70,000)
Co-design	PMB process lead and (if needed) municipal experts
Review	Advisory committee scores/ranks proposals
Implementation	Within ~18-month process (application - final reporting)

8.2.4. Amsterdamse Impuls Schoolpleinen (AIS) - Amsterdam Schoolyard Incentive

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
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- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Transferable checklist for green schoolyards
- Design guidance documents (PMB technical guidelines)
- Up to €70,000 subsidies.

INSTITUTIONAL EMBEDDING

yes/no
Part of Amsterdam's Coalition Agreement 2022–26

8.2.4. Amsterdamse Impuls Schoolpleinen (AIS) - Amsterdam Schoolyard Incentive

LESSONS LEARNED
- **Standardized criteria and expert support streamline transformation**

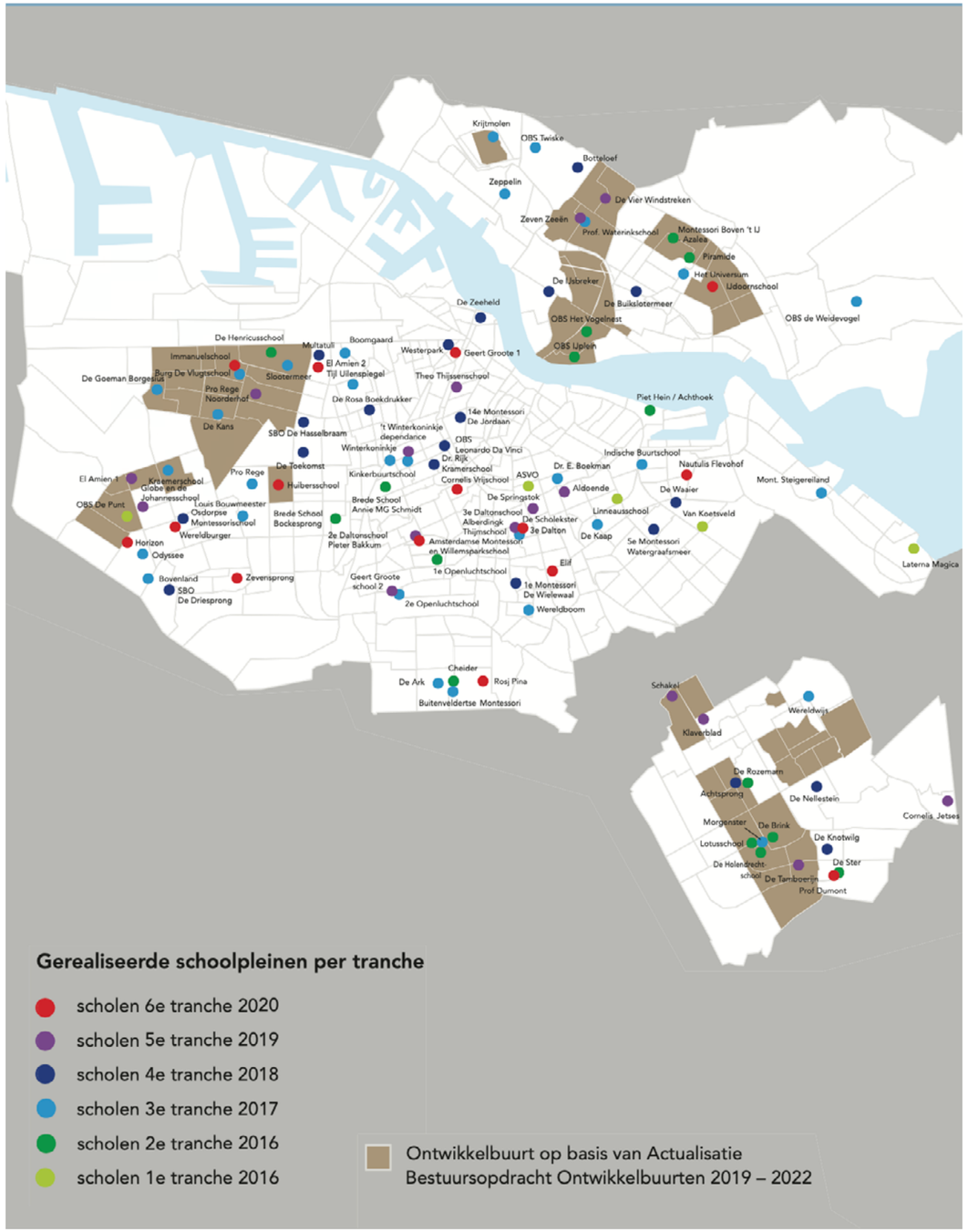
KEY BARRIERS
- Securing co-funding (80:20);
- Managing multiple subsidy streams; i
- Maintenance requirements

INNOVATION
- Institutionalized subsidy model with predefined criteria and in-kind expert support

TRANSFER POTENTIAL
- **High** – clearly documentable and modular scheme that other municipalities or regions can adapt using subsidy-plus-support co-development

REFERENCES

https://www.amsterdam.nl/pmb/opdrachten-projecten/amsterdamse-impuls/
https://openresearch.amsterdam/nl/page/74985/amsterdamse-impuls-schoolpleinen---kennisdocument
https://www.interregeurope.eu/good-practices/amsterdam-schoolyard-incentive#:~:text=The%20AIS%20is%20an%20annual,in%20planning%20their%20new%20schoolyards.



8.2.5. REFUGIS CLIMATICS - Climate Shelters in Schools

GENERAL INFORMATION & CONTEXT

Location	Barcelona, Spain
Climate Zone	Csa/Csb (Mediterranean – hot summers)
Year(s)	2019–2022 (UIA-funded; integrated into city scheme thereafter)
Type	Transformation project; Subsidy scheme; Policy advocacy
N. of schools	11
School level	Elementary Schools
Project Initiators	Barcelona City Council; Education Consortium; Public Health Agency; ISGlobal/UAB; UAB-ICTA; BCASA; UIA funding

SHORT DESCRIPTION

The project supports the adaptation of Barcelona to climate change in terms of extreme temperatures and heat waves. The project was funded by Urban Innovation Action (UIA), a European Commission programme as part of the 'Adapting schools to climate change through green, blue and grey'. The project aim is to convert 11 primary schools currently considered vulnerable to heat into climate shelters open to all city residents by implementing traditional solutions against heat in buildings and by transforming playgrounds into year-round "climate shelters" by implementing green (vegetation), blue (water points), and grey (shade structures and insulation) infrastructure. Guided by co-design with students & community. Interventions included opening schoolyards to residents during non-school periods, monitoring climate and health impacts, and integrating outcomes into municipal climate strategy.

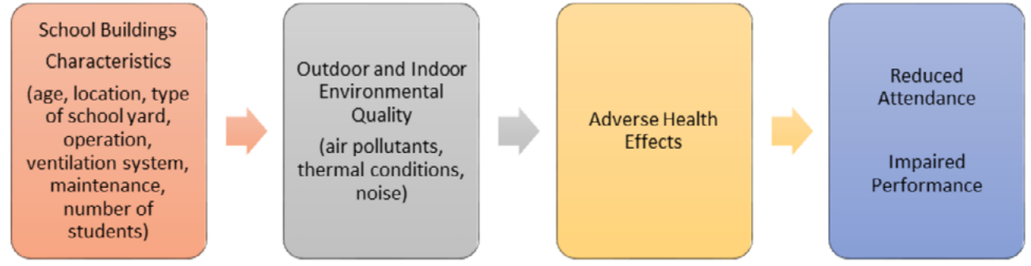
OBJECTIVES

- Convert 11 schoolyards into climate shelters;
- Reduce heat exposure; provide public access;
- Embed climate education;
- Evaluate health/environment benefits;
- Pilot replicability

PROCESS

- **Selection (risk-based)** — Schools selected via multi-criteria logic
- **Participatory Co-design** — Pupils + school community define needs and interventions
- **Implementation** — Implement combined measures in yard + building
- **Monitoring & Evaluation** — Sensors + mixed-method evaluation

8.2.5. REFUGIS CLIMATICS - Climate Shelters in Schools



CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
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- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Catalogue of blue-green-grey solutions;
- Environmental quality monitoring systems with Indicators sets
- Evaluation process

INSTITUTIONAL EMBEDDING

(**yes**/no)

- Incorporated into Barcelona Climate Plan with target to provide a climate shelter within 10-min walk by 2030; integrated into "Let's transform the schoolyards" municipal program that followed up

8.2.5. *REFUGIS CLIMATICS - Climate Shelters in Schools*

LESSONS LEARNED

- Co-design and living-lab model foster tailored solutions; however, it must be structured. "Participation" works when it is anchored to clear decisions (zones, uses, shade targets, access rules), otherwise it becomes symbolic and slows delivery.
- Opening to community increases equity and use;
- Hybrid solutions outperform single-lens greening. The green–blue–grey package acknowledges that in hot Mediterranean summers you need shade + evapotranspiration + water access + (sometimes) building measures to actually shift comfort
- Embedding scientific monitoring makes replication defensible and helps move from pilot to program.

KEY BARRIERS

- Coordinating multi-sector partners;
- Long-term operations & maintenance risk
- Ensuring long-term use;
- Evaluating health outcomes is complex

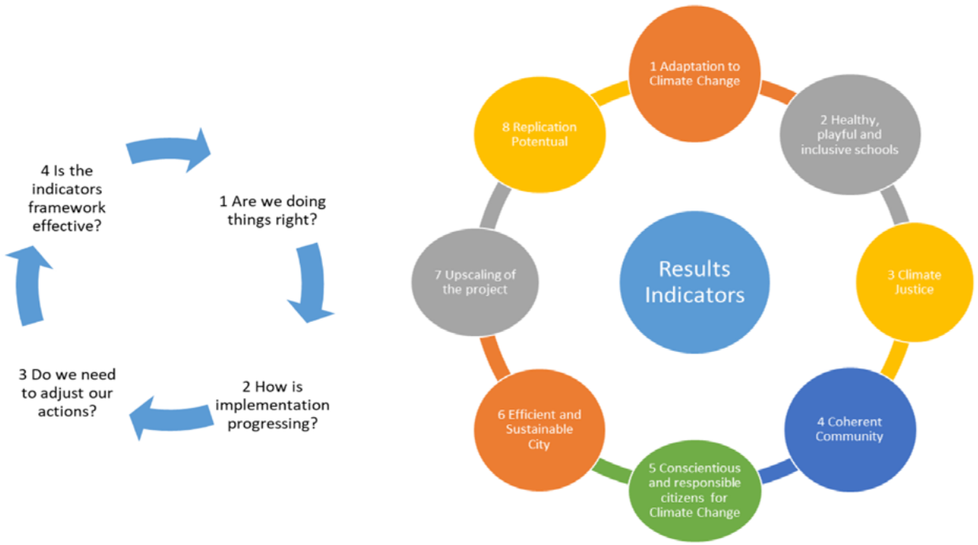
INNOVATION

- Triple-measures approach (green-blue-grey);
- Climate shelters concept– use of schools as community shelters;
- Scientific evaluation embedded;

TRANSFER POTENTIAL

- **High** – replicable across districts; supported by EU UIA framework; formal municipal adoption ensures sustainability of the model

REFERENCES https://www.uia-initiative.eu/en/uia-cities/barcelona-call3



8.2.6. OASIS project

GENERAL INFORMATION & CONTEXT

Location	Paris, France
Climate Zone	Csa/Csb – Mediterranean (hot summers)
Year(s)	2018–present (UIA pilot, 2019 municipal scaling ongoing)
Type	Transformation project; Subsidy scheme; Policy advocacy
N. of schools	10 pilot schools; 165 schools since 2017; 360 planned by 2030
School level	Preschool, Elementary, Middle
Project Initiators	City of Paris, The Council of Architecture, Urbanism and Environment of Paris (CAUE 75), The Paris Federation of the Ligue de l'Enseignement, and other stakeholders

SHORT DESCRIPTION

The OASIS project aimed to create a new solution for designing and transforming urban spaces to adapt to the effects of climate change. 10 pilot school playgrounds across the city of Paris were converted into cool islands using a combination of innovative technical and nature-based solutions. Each playground was transformed following a comprehensive co-design approach with pupils and educational communities. The project ambition is to contribute to addressing health risks associated with heat waves while fostering social cohesion at neighbourhood level.The project was launched in 2018 as part of Paris's Climate Adaptation Plan and funded by the UIA (2019–2022). Following the Pilot phase the City of Paris institutionalised the program as part of its resilience strategy and planning to reach all 770 schools by 2050 .

OBJECTIVES

- Revitalise neglected schoolyards
- Create attractive public spaces for recreation, education and civic activity
- Support meaningful and innovative educational use of schoolyards
- Cultivate significant public participation, including many community-based organisations, in both the design and stewardship of the schoolyards.

PROCESS

Participatory co-design	Co-design with pupils + educational community,
Pilot / prototyping	10 UIA "living-lab" pilots to develop a replicable method
Phased implementation	UIA pilot > municipal program scale-up
Monitoring & feedback	Impact measures (thermal, noise, biodiversity, wellbeing)

8.2.6. OASIS project

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- OASIS Maintenance Guide
- OASIS RECOMMENDATIONS BOOKLET
- OASIS Educational kits

INSTITUTIONAL EMBEDDING

yes/no
Embedded into Paris's Climate Adaptation Plan (2017); treated schoolyards as part of the **urban cooling network**—not just educational infrastructure.

8.2.6. OASIS project

LESSONS LEARNED

- Co-design ensures local adaptation;
- Living lab model informs scalable solutions;
- Institution-level support enables long-term success

KEY BARRIERS

- Resource constraints to replicate pilot intensity;
- Securing standards vs. budget and balancing high quality and coverage

INNOVATION

- OASIS holistic and institutionalized approach **redefined schoolyards** as **urban climate infrastructure**, bridging **education, health, and spatial equity** with climate resilience policy.
- Legally and physically **opened schoolyards to the public** after hours to serve as **cool spaces during heatwaves**, unlike many earlier projects that were limited to school use.
- Strong interdepartmental and cross-sector collaboration (education, health, urban planning, design, science, and public works) for **institutionalized change**.
- Developed a **dedicated education kit** that links climate adaptation, outdoor learning, and environmental stewardship, systematized across age levels.

TRANSFER POTENTIAL

- High – detailed methodology, replicable through living-lab structure and institutional frameworks

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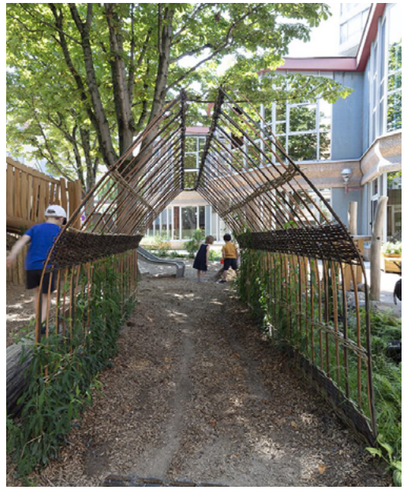
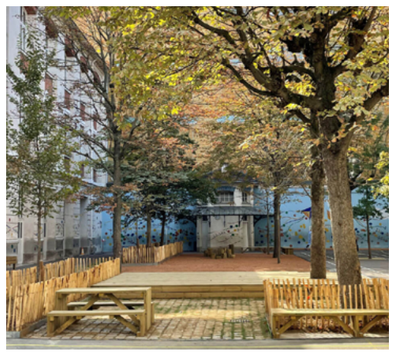




8.2.7. MICOS programme

GENERAL INFORMATION & CONTEXT

Location	Madrid, Spain
Climate Zone	Csa/Csb – Mediterranean (hot, dry summers)
Year(s)	Initiated ~2016; guideline published Dec 2017; pilot in 2018–19
Type	Transformation project, Resource hub, Policy advocacy
N. of schools	3
School level	Elementary
Project Initiators	Madrid Salud (Municipal Health); Development, Environment, Education Boards; District Councils; PEZ Arquitectos; community representatives

SHORT DESCRIPTION

MICOS piloted a participatory, co-designed method to transform schoolyards and adjacent access areas of three public primary schools into healthier, climate-adaptive, inclusive educational and social spaces. It was documented in the "Guía de Diseño de Entornos Escolares" (Dec 2017).

OBJECTIVES

- Turn schools into hubs for neighborhood and community development
- Promote healthy lifestyles,
- Create healthy, play and social environments
- Stimulate positive social development
- Improve safety and accessibility
- Integrate climate adaptation in school design

PROCESS

Participatory co-design	Strong community involvement
Pilot / prototyping	3 pilots
Phased implementation	yes (mostly due to limited budget)
Monitoring & feedback	Limited evaluation

8.2.7. MICOS programme

CHALLENGES ADDRESSED

Climate-related hazards	
Environmental stressors	
Health & Development	
Education	
Spatial Justice	

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

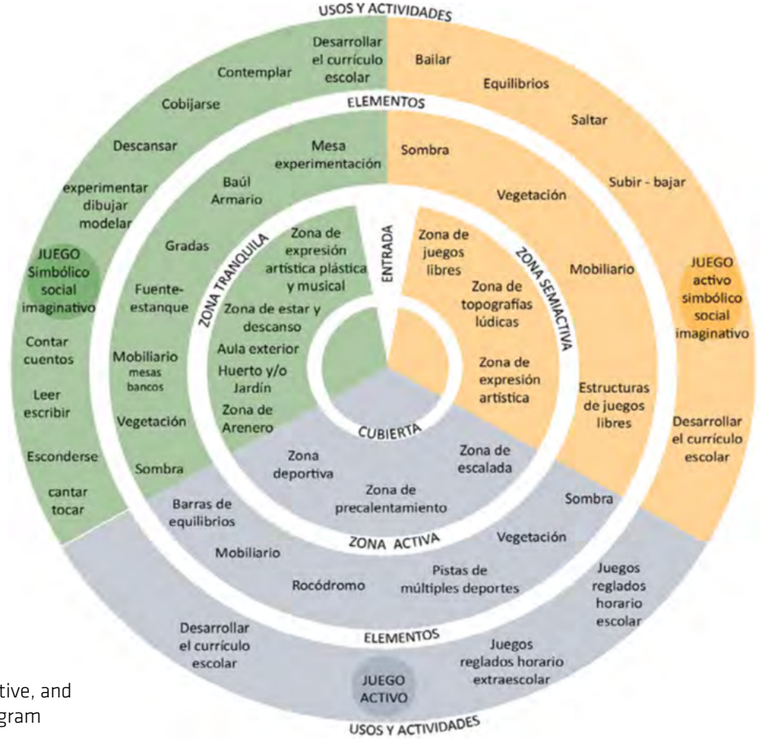
- Design Guide (Guía de Diseño de Entornos Escolares)
- Tools for analysis and participatory planning

INSTITUTIONAL EMBEDDING (yes/no)

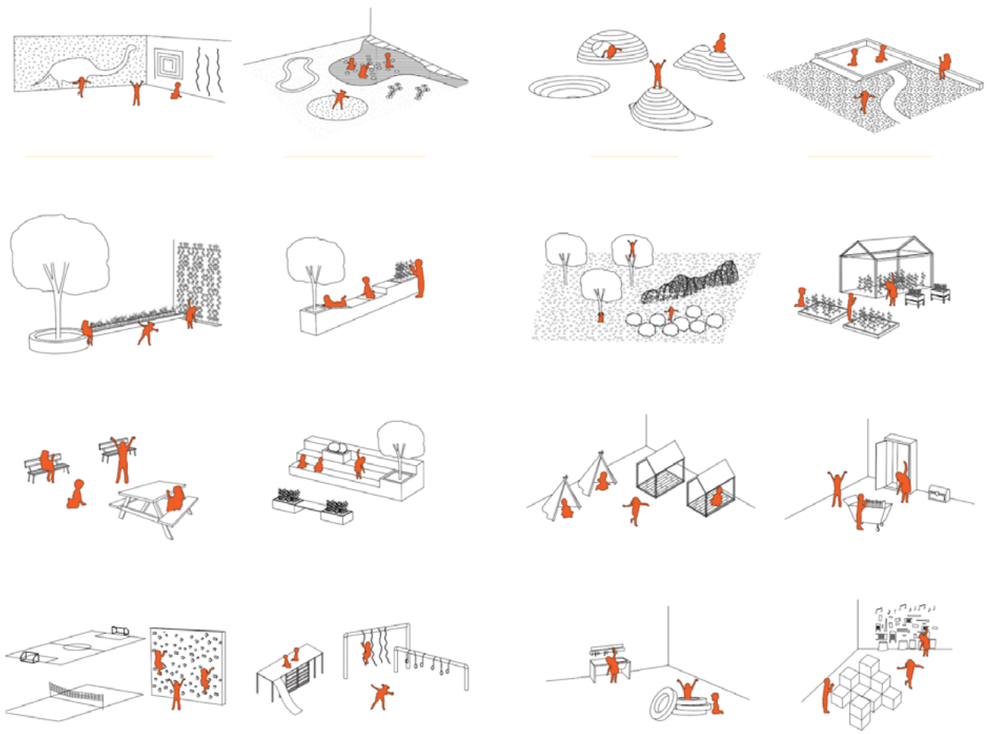
- Aligned with Madrid Ciudad de los Cuidados, Plan A Climate Strategy, and urban regeneration goals

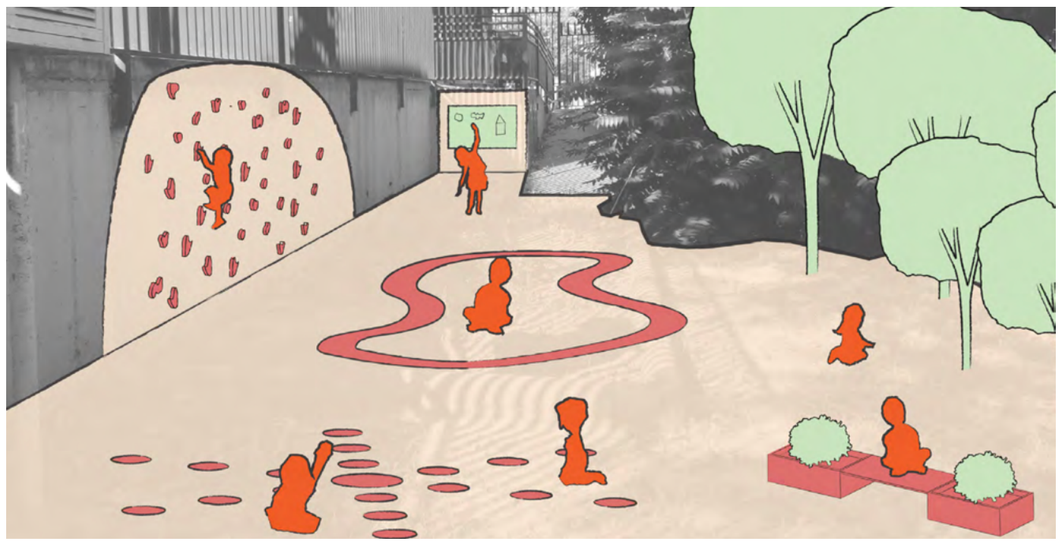
8.2.7. MICOS programme

LESSONS LEARNED	ø Participation ensures relevance and ownership; ø Engaged governance enables systemic transformation
KEY BARRIERS	ø Budget variability across districts; ø phased execution; ø administrative coordination complexity
INNOVATION	ø **The direct inclusion of school access streets as part of the climate- and health-focused transformation of the school environment**
TRANSFER POTENTIAL	ø High – master plans and guide can inform schools and cities across Spain
REFERENCES	https://estrategiaurbana.madrid.es/proyecto-micos-2/ https://estrategiaurbana.madrid.es/wp-content/uploads/2021/03/guia_diseno_entornos_escolares_opt-1.pdf

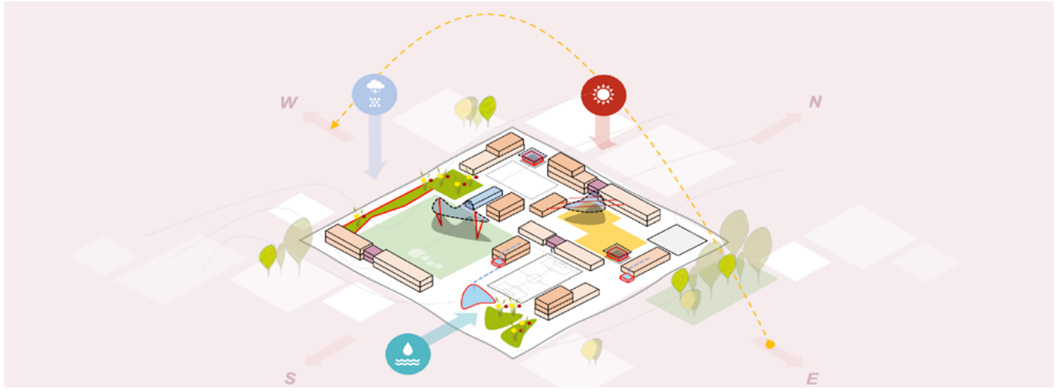


Active, semi-active, and quite zones diagram





8.2.8. Climate Resilient Schools



GENERAL INFORMATION & CONTEXT

Location	London, United Kingdom
Climate Zone	Cfb – Temperate oceanic
Year(s)	Launched 2020 (guidance); pilot CAPs in 2023
Type	Transformation support, Resource hub, Policy Advocacy
N. of schools	Indirect: 60 schools received tailored Climate Action Plans (CAPs); 564 SuDS rain planters installed across 72 schools
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Greater London Authority (Mayor's Office); Department for Education; Thames Water; ARUP; Meristem Design; participating schools

SHORT DESCRIPTION

Climate Resilient Schools is a multi-partner programme providing technical guidance, CAPs, and green infrastructure measures (e.g., SuDS planters) to make up to 100 London schools more resilient to flooding, water scarcity, and overheating. In 2020, the Greater London Authority (GLA) commissioned Arup to develop guidance for London schools on the measures they can take to adapt to climate change. Arup researched and engaged with the London school and community, developing an adaptation planning approach, which included physical changes, operational and behavioural measures and funding opportunities.
In 2023, tailored climate action plans (CAPs) for 60 schools as part of the GLA's Climate Resilient Schools (CRS) programme were developed identifying the most significant climate change impacts and risks facing each school – covering overheating, flooding and water scarcity.

OBJECTIVES

- Improving water efficiency,
- Reducing surface water flood risk,
- Helping schools create climate adaptation plans
- Teaching children the importance of climate adaptation

PROCESS

Stakeholder engagement	Schools/community input used to shape guidance + plans
Pilot / prototyping	Pilot CAPs + pilots of SuDS planters;
Phased implementation	Citywide guidance > targeted CAPs > implementation
Monitoring & feedback	Environmental monitoring network via EduStation

8.2.8. Climate Resilient Schools

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
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- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Climate adaptation plans for schools" guidance PDF
- School-specific CAPs and measure compendium
- SuDS installation case studies
- EduStation weather and data platforms

INSTITUTIONAL EMBEDDING (yes/no)

- Co-funded by Mayor and DfE; uses London Climate Risk Mapping; aligns with NAP and strategic urban resilience planning

8.2.8. *Climate Resilient Schools*

LESSONS LEARNED
- Tailored CAPs build both risk awareness and operational feasibility
- SuDS planters are scalable, practical adaptations
- Student-led monitoring embeds learning in resilience

KEY BARRIERS
- Finance and resources for widespread implementation
- Operational staff capacity and skills
- Data-quality challenges for CAP precision

INNOVATION
- Combining guidance, CAPs, and physical SuDS implementation
- Integration of monitoring systems and STEM learning
- CAPs (Climate Adaptation Plans) for London schools include measures for **natural ventilation, shading, reflective surfaces, and cool roofs** – targeting overheating mitigation **inside** classrooms. This approach ensures that the **climate adaptation is embedded across the entire school environment,** targeting **indoor thermal comfort, building-level resilience**, and **curricular integration**, not just outdoor spaces.
- London's program is **one of the very few** that **includes water saving as a specific goal**, not just stormwater drainage or infiltration adding a **climate mitigation dimension**

TRANSFER POTENTIAL
- High – model (guidance K CAP K pilot K scale) and SuDS system replicable in other municipalities;

REFERENCES

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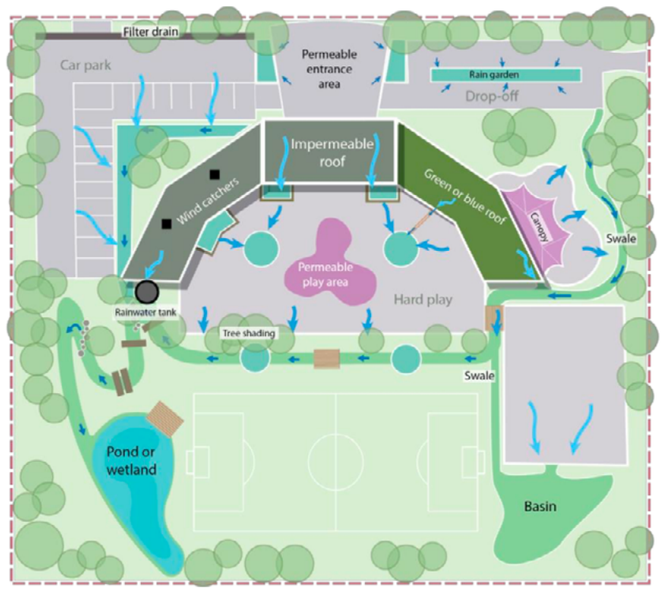

Figure 2: Adaptation measures in a spacious school site
adapted from GLA 2019[11], courtesy of Robert Bray Associates

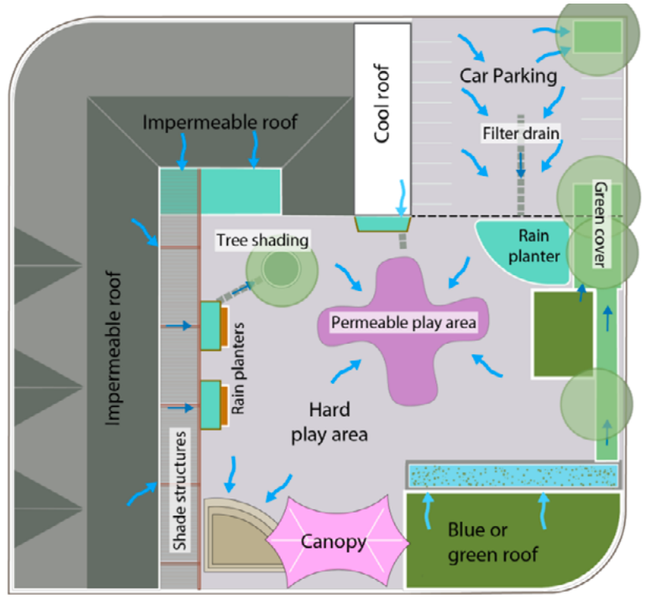

Figure 3: Adaptation measures in a compact school site
adapted from GLA 2019[11], courtesy of Robert Bray Associates

8.2.9. Opération Ré-création

GENERAL INFORMATION & CONTEXT

Location	Brussels, Belgium
Climate Zone	Cfb – Temperate oceanic
Year(s)	2021; first projects in 2022
Type	Transformation Project; Subsidy Scheme; Resource Hub
N. of schools	45
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	Brussels Environment; Perspective.brussels; Bubble. brussels; school communities (students, teachers, parents);

SHORT DESCRIPTION

A regionally funded initiative to transform 20 (19 selected) concrete schoolyards into green, biodiverse, climate-resilient, and inclusive playgrounds through participatory co-design, community workshops, and use of Pic2School & Oasis pedagogical tools.

OBJECTIVES

- From climate resilience perspective:
  - improve soil permeability and water management
  - provide cooling for students and local residents during heatwaves
  - gradually strengthen biodiversity and the green network of the regional territory, thanks to the creation of semi-natural habitats for insects and birds.
  - limit the spread of noise
- Improve user well-being, learning through contact with nature, the development of mixed play and relaxation areas,
- Make green spaces accessible to local residents for activities outside of school hours.

PROCESS

- **Target + select** – Schools targeted in green-space-deficit areas
- **Participatory co-design** – Co-develop a budgeted courtyard plan via workshops
- **Phased implementation** – Soil/technical checks & support through procurement, execution, and site supervision
- **Monitoring & feedback** – -

8.2.9. Opération Ré-création

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
- **Playground Redesign:** Balancing new play structures with natural play zones (logs, stumps, boulders)
- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Bubble website with project cases and tools
- Pic2School participatory design tool
- Educational kits and workshop guides

INSTITUTIONAL EMBEDDING (yes/no)

- Part of GO4Brussels 2030

8.2.9. Opération Ré-création

LESSONS LEARNED

- **Tactical urbanism and playful co-design tools** (e.g., roleplay, mapping games) are effective in engaging children and educators, making spatial redesign a **learning process** as well as a planning one.
- Strong cross-sector collaboration among **education departments, urban planners, environmental organizations, and NGOs** was critical to overcoming fragmentation.
- **Equity goals** (e.g., targeting schools in high-density or low-green-access areas) must be operationalized in the selection process to ensure fairness

KEY BARRIERS

- Need for sustained community engagement and funding continuity

INNOVATION

- Pic2School and educational gaming tools

TRANSFER POTENTIAL

- High – tools, kits, and participatory framework available online; project model replicable across urban regions

REFERENCES

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https://www.bubble.brussels/operation-re-creation-4-chantiers-acheves/
https://k-s.be/ruimte-omgeving/school-schoolomgeving/pic2school-een-inspraaktool-om-schoolspeelplaatsen-te-ontwerpen-/
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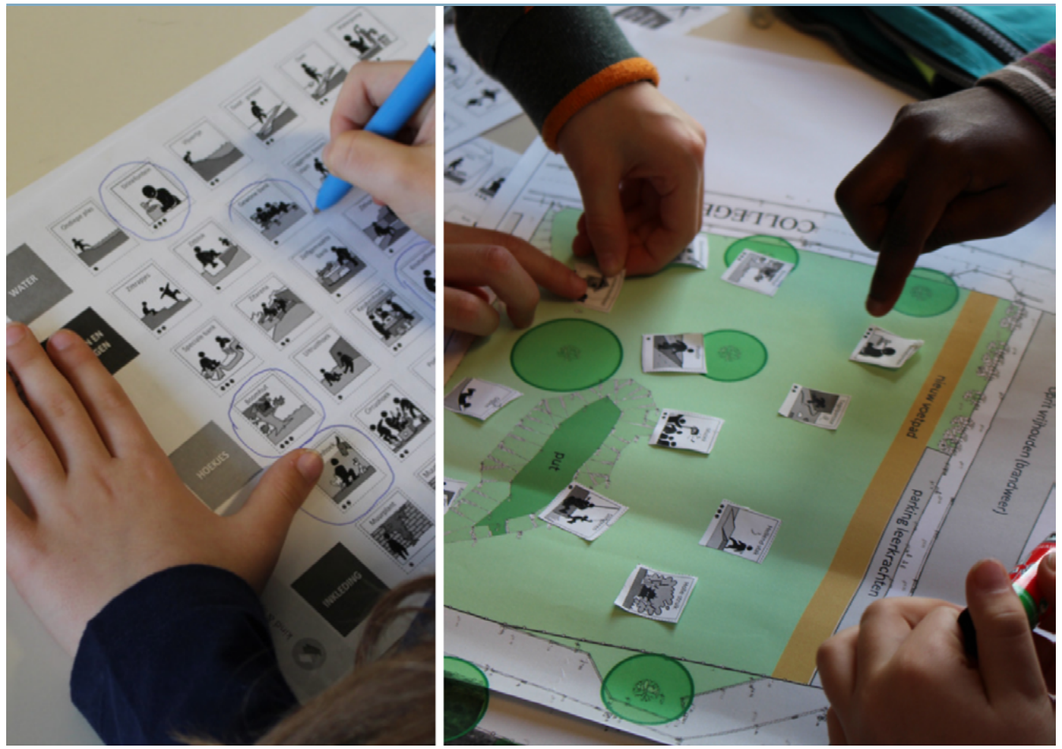

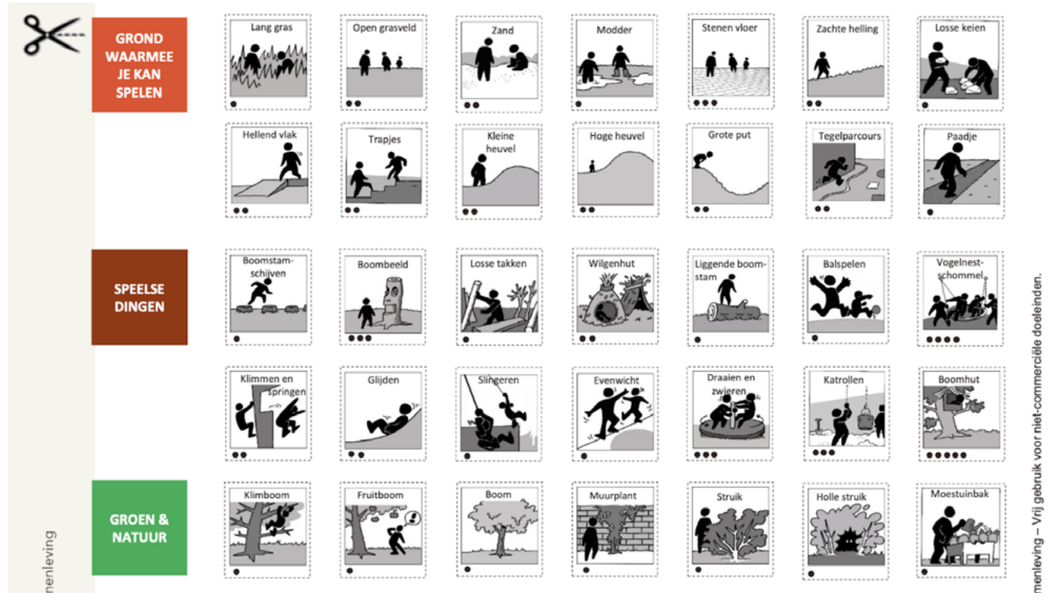

8.2.10. Cool Schools

GENERAL INFORMATION & CONTEXT

Location	Netherlands, Belgium, France, Spain
Climate Zone	Koppen classification
Year(s)	2022-2025
Type	Research project (HORIZON 2020 Applied Research Project)
N. of schools	?
School level	Kindergarten, Elementary, Middle, and High School
Project Initiators	-

SHORT DESCRIPTION

COOLSCHOOLS is an applied-research project aiming to analyse the multiple co-benefits of implementing nature-based solutions (NbS) for climate adaptation in school environments. The project examines how these nature-based climate school shelters can serve as drivers of transformation at larger urban scales through an interdisciplinary approach that focuses on the needs and perspectives of children and youth.

OBJECTIVES

- Cooling through green infrastructure
- Improve health
- Showcase multiple benefits of implementing NbS in Schoolyards
- Develop transferable models for NbS implementation in schools.

PROCESS

Frame + select living labs	Study cities + pioneer programmes
Research	Baseline mapping + mixed-method diagnosis
Co-creation	Co-produce knowledge with school communities
Synthesis	Tools, guidelines, and policy uptake

8.2.10. Cool Schools

CHALLENGES ADDRESSED

- **Climate-related hazards**
- **Environmental stressors**
- **Health & Development**
- **Education**
- **Spatial Justice**

STRATEGIES & SOLUTIONS ADOPTED

- **De-paving & Greening:** Removing sections of asphalt to create green pockets or lawns for recreation, stormwater management, cooling, and education.
- **Shade Trees & Gardens:** Planting trees and shrubs for shade, biodiversity, and improved aesthetics.
- **Stormwater Management:** Integrating rain gardens, swales, and permeable surfaces to address urban flooding and improve water quality.
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- **Outdoor Classrooms & Learning Stations:** Incorporating features such as seating areas, native plant beds, and interactive signage to support curriculum.
- **Community:** Flexible gathering spaces for both school and neighborhood use.
- **Murals & Environmental Art:** Including student-created artwork to connect cultural identity with the newly greened space.

OUTPUTS

- Policy briefs, co-design toolkit, urban and educational guidelines, online repository of case studies, integrated framework for NbS scaling in school environments.

INSTITUTIONAL EMBEDDING

(**yes**/no)

- Cool Schools works in collaboration with city councils (e.g., Barcelona, Paris, Rotterdam) and feeds into local adaptation policies. Supports alignment with EU Climate Adaptation Strategy and Urban Agenda.

8.2.10. *Cool Schools*

LESSONS LEARNED

- School-based NbS can serve as hubs for wider urban resilience.
- Participatory design increases local ownership and inclusivity.
- Cross-sector governance is crucial for success.
- Health and education benefits must be documented and communicated clearly to scale adoption.

KEY BARRIERS

- Institutional fragmentation across sectors.
- Varying capacities and readiness across schools.
- Limited long-term monitoring frameworks.
- Need for context-specific adaptation of tools and approaches.

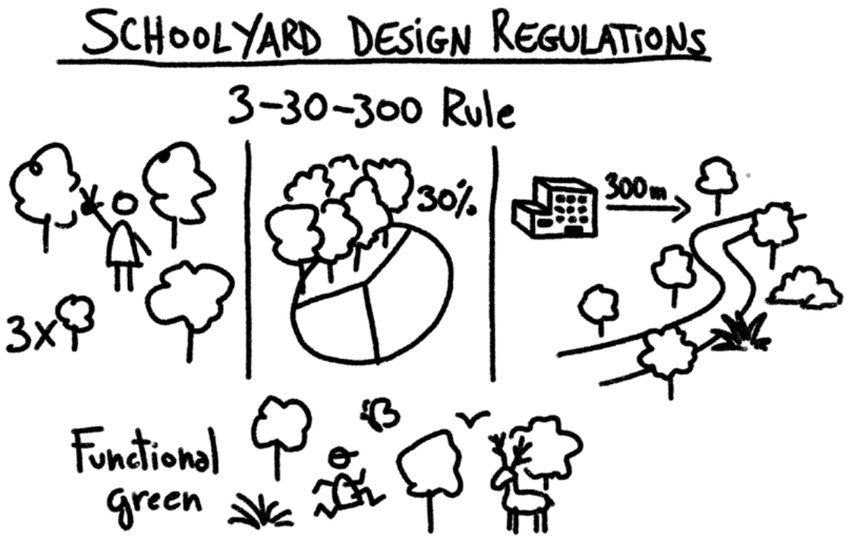
INNOVATION

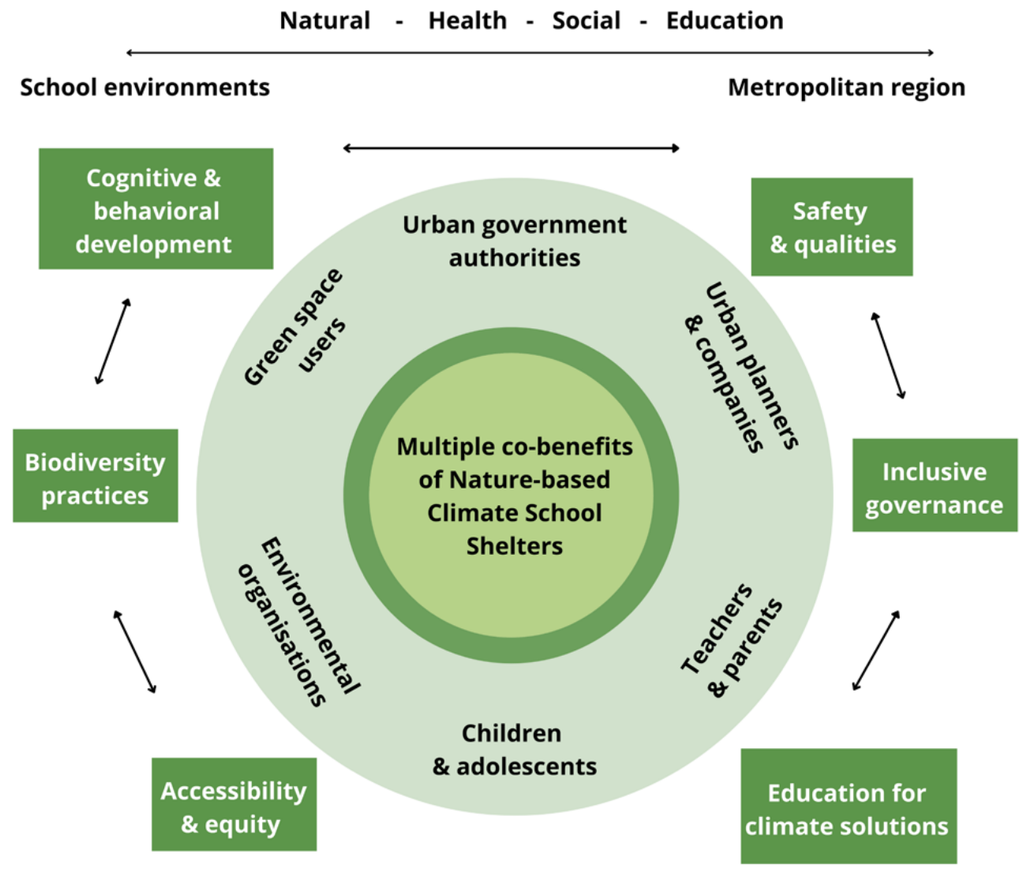
- Co-creation model grounded in scientific monitoring.
- Child-centered participatory research at scale.
- Integration of NbS into educational planning.
- Explicit framing of schoolyards as urban NbS infrastructures.

TRANSFER POTENTIAL

- **High** – Tools and findings are being developed specifically for EU-wide applicability. The framework is modular, open-access, and grounded in empirical case studies across different climate zones and socio-political settings.

REFERENCES https://coolschools.eu/





8.3. Lessons Learned

The growing body of European best practices in schoolyard transformation reveals a **shared momentum to redesign educational outdoor spaces in response to the intersecting challenges of climate change, health inequity, urban densification, and academic innovation**. While local approaches differ based on governance structures, environmental contexts, and political will, certain strategic trends emerge consistently across initiatives. These include participatory design, integration of Nature-based Solutions (NbS), alignment with climate adaptation goals, and a systemic orientation that treats schoolyards as both learning environments and critical urban infrastructure.

Across the cases, some stand out for their **innovative framing or expanded scope**. For example, **London's Climate Resilient Schools programme** is one of the few to systematically deliver **Climate Adaptation Plans (CAPs)** for schools, incorporating not just outdoor space redesign, but also **building-level measures** (e.g., cool roofs, natural ventilation), **flood mitigation,** and even **water-saving strategies**, demonstrating a whole-campus approach that merges adaptation, mitigation, and education.

The **MICOS programme in Madrid** extends the transformation beyond the school gates, addressing **school access streets** as part of the intervention. This rare inclusion highlights the importance of **peripheral urban conditions**, such as safety, accessibility, and permeability, in shaping children's experiences of the school environment. The project serves as a model for rethinking the relationship between schoolyards and surrounding public space, and for embedding health and equity into broader urban design.

The **Refugis Climàtics initiative in Barcelona** and the **OASIS project in Paris** have gained widespread recognition for framing schoolyards as **climate shelters**, linking them to urban heat mitigation strategies and public access policies. However, Refugis Climàtics goes a step further by introducing **air quality monitoring and indoor–outdoor climate sensors**, directly addressing a l**ocalized but critical environmental stressor—urban air pollution**. In doing so, the project not only adapts to rising temperatures, but also foregrounds the **synergistic effects of heat and air quality** on children's health, bridging a significant gap in climate-health design.

Beyond these emblematic cases, many other cities and regions are **mainstreaming schoolyard transformation** through **institutional mechanisms**. For instance, **Antwerp's EcoScholen, Brussels' Opération Ré-Création,** and the **Groenblauwe Schoolpleinen** initiative in the Netherlands have formalized their approaches through **subsidy schemes, technical guidance,** and **structured co-design protocols**. These programs rely on **quality frameworks** (e.g., the 8 Design Principles of Blauw Groen Vlaanderen) to ensure consistency across contexts, enabling scalable implementation without losing place-based sensitivity.

A growing number of municipalities are also incorporating schoolyard transformation into their **urban climate** and **spatial policies**, as seen in **Amsterdam's AIS program**, which aligns its interventions with both the **coalition agreement** and **city-wide resilience goals**. Similarly, **Paris** has committed to transforming all 770 schoolyards by 2050 as part of its **urban cooling strategy**, while **Barcelona** is embedding climate shelters into its **broader climate** and **health plans.**

A particularly valuable insight from this landscape is the rise of **hybrid projects** that combine educational innovation, community co-design, environmental monitoring, and policy integration. Projects like Evergreen's Climate Ready Schools in Canada and Opération Ré-Création in Brussels incorporate pedagogical tools, public access models, and evaluation systems. These cases showcase the importance of multi-solving approaches—where single interventions generate climate resilience, educational value, social cohesion, and environmental awareness simultaneously.

The analysis of best practices suggests that systemic schoolyard transformation is not only possible, but increasingly replicable, especially when it is:

- Rooted in participatory design,
- Informed by local climate and health risks,
- Supported by policy frameworks and funding mechanisms,
- Linked to education reform and equity agendas, and
- Framed as a catalyst for broader urban resilience and regeneration.

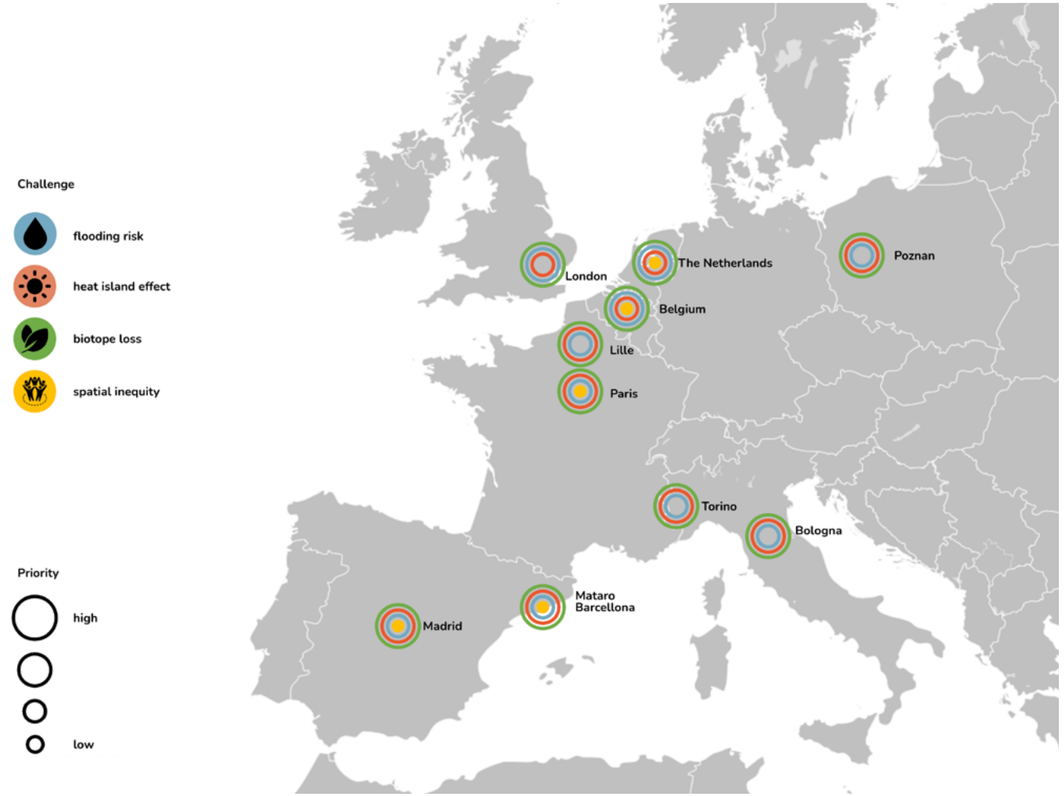
Flg 8.3. Schoolyards transformations in the past 10 years in Europe.

8.3.1. Key Challenges, Objectives, and Responses in Different European Contexts

Across European best practices, there is growing consensus on the interconnected nature of environmental, health, and social challenges in school environments. The shared key issues are:

- Climate change (heat, flooding, drought, stormwater),
- Child health and child development (physical inactivity, mental stress, access to nature, exposure to pollution, stress),
- Education (curriculum integration, outdoor learning, nature literacy)
- Systemic inequalities (accessibility, socio-spatial inequality, access for underserved populations).

While these themes recur, localised expressions of these challenges showcase diverse priorities.



Flg 8.3.1. Interventions focus of schoolyards transformations in different EU contexts.

In **Southern Europe,** where extreme heat and urban densification are pressing, the focus is often on urban cooling and public access. Both Barcelona's Refugis Climàtics and Paris' OASIS treat schoolyards as climate shelters—cool islands open to the public during heatwaves. This framing integrates public health, climate resilience, and civic function, embedding schoolyards into broader climate adaptation infrastructure.

In **Western and Central Europe**, especially Belgium and the Netherlands,climate challenges are often less extreme, but stormwater management, biodiversity, and educational integration dominate the agenda. Projects such as Blauw Groen Vlaanderen, Groenblauwe Schoolpleinen, and EcoScholen Antwerp prioritize resilience through nature-based solutions, funding mechanisms, and curricular alignment, while also ensuring equitable access across schools.

In **Northern Europe,** such as Amsterdam, and to a certain extent in London, objectives are explicitly tied to municipal climate strategies and public health policy. The AIS programme not only aims to improve outdoor play and learning but explicitly contributes to city-wide green space and heat reduction targets. London's Climate Resilient Schools takes this further by addressing indoor comfort, water-saving, and long-term institutional climate planning, setting a precedent for whole-school adaptation frameworks.

Table 8.3.1.a Key Challenges and Objectives Across Diverse Contexts

Geographic location	Key Challenges	Shared Objectives	Differences
North America (USA, Canada)	Urban heat, impermeable surfaces, physical inactivity, lack of nature access	Community-led transformation, equity in greening, outdoor learning, climate adaptation	Strong focus on grassroots/ community-driven change and policy advocacy (e.g., Community Schoolyards™, Living Schoolyards Act)
Northern/Central Europe (Belgium, Netherlands, Germany)	Urban heat, stormwater, lack of outdoor learning, maintenance, biodiversity loss	Integrate schoolyards into climate, education, and health policy; create structured funding models	Institutional and subsidy-based approaches with predefined design principles
Southern Europe (Spain, France, Italy)	Urban heat islands, educational inequity, socio-spatial vulnerability	Schoolyards as climate shelters, mental health support, public access during heatwaves	Framed as part of urban resilience and public health infrastructure
UK (London)	Overheating, flooding, lack of classroom comfort	School-wide CAPs, technical guidance, water-saving solutions	Emphasis on whole-school climate planning, including indoor and outdoor spaces

Table 8.3.1.b Climate Risk–Design Response Mapping: Several leading practices directly link specific climate risks to targeted design strategies illustrating how schoolyards can act as climate infrastructure responding to local risks and creating added value.

Hazard	Design Responses	Example Projects
Urban Heat	Tree canopy, shade structures, permeable surfaces	OASIS (Paris), Refugis Climàtics
Flooding/Stormwater	Rain gardens, bioswales, sponge grounds, water play	Evergreen Climate Ready, Brussels
Drought	Native planting, efficient irrigation, water retention	Amsterdam, Groenblauwe Schoolpleinen
Air Pollution	Vegetation buffers, activity zoning, monitoring sensors	Refugis Climàtics (Barcelona)

8.3.2. Key barriers identified

While the best practices documented across Europe provide valuable models and inspiration, they also highlight a consistent set of barriers that can hinder or delay the transformation of schoolyards into climate-resilient, health-promoting environments. Understanding these barriers is essential for shaping strategies that are not only ambitious but also realistic, context-sensitive, and resilient over time.

The barriers observed across multiple projects can be grouped into five broad categories:

- **Maintenance and Long-term Stewardship**: Lack of long-term funding, staff capacity, and clear responsibilities often hinders the care of green and complex infrastructure.
- **Funding Limitations and Uneven Access to Resources:** Even with subsidies, some schools—especially in vulnerable areas—struggle to meet co-financing requirements or sustain upgrades over time.
- **Institutional and Bureaucratic Constraints**: Bureaucratic rigidity, limited cross-sector coordination, and administrative silos slow or complicate implementation.
- **Community Engagement Challenges:** Inconsistent participation, unclear roles, or engagement fatigue can undermine co-design and long-term ownership.
- **Monitoring, Evaluation, and Evidence Gaps:** High-cost or complex evaluation tools are often difficult to maintain; many schools lack practical methods to track climate or health impacts.

These barriers underscore the fact that schoolyard transformation is not simply a matter of physical redesign, it requires governance innovation, capacity-building, long-term planning, and institutional embedding. While design and policy frameworks are essential, they must be supported by operational mechanisms that address day-to-day realities of schools and communities. These are not constraints to innovation—they are design parameters that must be addressed explicitly to make transformation realistic, inclusive, and lasting.

8.3.3. Methods and Processes: Toward a Transferable Methodology

Most transformation projects follow a recognizable but flexible sequence of transformation:
Strategic framing (selecting the school/site based on environmental and social data)
Stakeholder alignment and engagement (bringing together departments, school staff, students, and partners)
Participatory co-design (including technical and community-driven design processes)
Implementation and phasing (often in pilots, with modular scaling strategies)
Activation and programming (ensuring the space is used, celebrated, and linked to learning)
Monitoring and feedback (evaluating impact, refining governance, scaling where relevant)

Understanding these steps helps ensure a repeatable and adaptable process, while also allowing for entry points at different levels of readiness (e.g., from temporary greening to full redevelopment). From the analysis several patterns emerge:

- **Co-design and Participation** are central across the board. Whether in Barcelona's Living Lab schools, Brussels' Opération Ré-Création, or Amsterdam's AIS, co-design has proven essential to ensuring local ownership, child-relevance, and long-term care. Many programs explicitly include students, educators, and families in the early design phases through workshops, prototypes, and decision-making tools (e.g., Pic2School, mapping exercises, child interviews).
- **Pilot-to-scale** strategies are common and successful. Many cities, such as Paris, Barcelona, Amsterdam, and Brussels, begin with a limited number of test schools, evaluate outcomes, and then institutionalize the program into policy and annual funding cycles. This phased approach enables iteration, learning, and systemic integration.
- **Policy-aligned subsidy schemes**, accompanied by technical support, are particularly prominent in Belgium and the Netherlands. Programs like Groenblauwe Schoolpleinen and Blauw Groen Vlaanderen offer not only financial support but also design principles, expert coaching, and visual toolkits, enabling even resource-constrained schools to participate effectively.
- **Integration of science and monitoring**—such as in Refugis Climàtics (with air quality and climate sensors) and London's CRS (with Climate Adaptation Plans)—ensures evidence-based adaptation. These practices emphasize the need to quantify climate and health impacts and to link design with measurable outcomes.
- **Cross-sector collaboration.** Effective projects connect education departments, health agencies, urban planning authorities, and scientific institutions—breaking silos to create holistic, context-responsive solutions.

These methodological patterns together create a base for a transferable model, not through one-size-fits-all design, but through a framework of principles, flexible tools, and a systemic governance approach adaptable to different urban and climatic realities.

Table 8.3.3. Summary of Methods and Processes.

Effective methods identified	Characteristics	Trnasferability potential
Co-Design & Participation	Used in nearly all cases	Encourages ownership, enhances relevance; adaptable in all settings
Pilot K Scale Models	Common in Paris, Barcelona, Amsterdam, Brussels	Allows testing and adaptation; valuable for phased implementation
Subsidy + Technical Support Schemes	Flanders, Amsterdam, Brussels, Antwerp	Combines funding with guidance to ensure quality outcomes; highly replicable
Living Lab Approaches	Refugis Climàtics, OASIS, MICOS	Supports monitoring, innovation, and iterative learning
Cross-sector Governance	Seen in Barcelona, Paris, London	Institutional coordination enhances policy embedding and systemic change

Effective methods identified	Characteristics	Trnasferability potential
Research-Informed Guidelines	Green Schoolyards America, C&NN, CRS London	Evidence-based frameworks, monitoring, and CAPs ensure policy relevance
Selection criteria (incl. Health and climate hazard mapping)	Several best practices (e.g. Refugis Climàtics, OASIS, AIS Amsterdam) use spatial data (e.g. urban heat exposure, vegetation cover, air pollution, socio-economic vulnerability) to identify priority schools for interventions.	Easily adaptable in cities with GIS capacity or climate-health datasets. Useful to align schoolyard upgrades with urban climate adaptation and public health goals and to ensure climate justice.

8.3.4. Key Insights and Recurring Strategies for a Systemic, Replicable Approach

From analysing the different cases, several key strategies and success factors emerge that can inform a replicable approach to schoolyard transformation. These have been synthesised into the following elements :

1. **Climate Adaptation Solutions & Multifunction Design**
   - Depaving, permeable surfaces, shade planting, and habitat creation are widely used to combat urban heat, reduce runoff, and increase biodiversity.
   - Many projects emphasize multi-functionality, where each intervention serves climate, health, and educational goals (e.g., sponge yards in Canada, biodiversity gardens as science labs, stormwater gardens doubling as play areas).
2. **Flexible and Inclusive Zones**
   - Successful schoolyards include zones for active play, quiet reflection, exploration, and social interaction, addressing diverse needs across age, gender, and neurodiversity (e.g., Brussels, Paris, Barcelona).
   - Attention to gender equity and inclusive access is particularly evident in projects influenced by the Children & Nature Network or local equity planning initiatives.
3. **Opening Schoolyards to the Community**
   - Many cities have adopted policies that open schoolyards to public use during non-school hours, creating shared, safe, and green spaces—a key measure of urban justice and resilience (AIS, NYC, Paris, Brussels).
4. **Monitoring and Educational Integration**
   - Embedding pedagogical tools, environmental literacy curricula, and even student-led monitoring systems (e.g., CRS London's EduStation) allows the schoolyard to become a learning landscape and an engine for climate culture change.
5. **Governance and Policy Tools**
   - Providing subsidies tied to technical criteria (e.g., 8 Design Principles) ensures quality and standardization while allowing for local adaptation.
   - Creating municipal mandates and aligning climate plans (e.g., Paris 2050 target, Barcelona Climate Plan, Amsterdam coalition agreement) anchors projects within the long-term city strategy.
6. **Collaborative Design & Co-Creation:** One of the most notable shifts in successful European projects is the transition from top-down design to participatory and inclusive processes.
   - The roles of key actors, including children, teachers, school staff, families, designers, and municipal actors, are increasingly seen as co-creators, not just stakeholders.
   - Methods: workshops, mapping, prototyping, and roleplay are frequently used to ensure the spaces reflect real user needs.
   - Lessons learned: Early and meaningful engagement correlates with increased usage, pride, and long-term maintenance.

8.3.5. Innovation Highlights and Strategic Differentiators

Innovation in best practices takes many forms: policy (subsidy frameworks), technology (sensors, monitoring dashboards), governance (living labs), and pedagogy (climate education kits). However, several initiatives stand out for their unique contributions to the evolving practice of schoolyard transformation:

- **London's CRS** is perhaps the only case where indoor climate mitigation and water savings are explicitly addressed in school adaptation plans, pushing the boundary of schoolyard transformation into building performance and resource management.
- **Madrid's MICOS** includes school access streets and arrival areas in its scope, highlighting the importance of safe and climate-friendly threshold spaces, a crucial insight for cities dealing with traffic, heat, and social inequity.
- **Barcelona's Refugis Climàtics** uniquely integrates air quality sensors and aligns schoolyard transformation with mental health and emergency preparedness, reflecting a nuanced understanding of compound climate-health vulnerabilities in dense Mediterranean cities.
- **Brussels' Opération Ré-Création** is innovative in combining tactical urbanism, pedagogical gaming tools, and structured community activation, offering a template for engaging children in spatial literacy and co-design.
- The **8 Design Principles** adopted in Belgium and the Netherlands offer a standardized yet flexible quality framework that can be adopted by other municipalities to scale schoolyard transformation without sacrificing ecological or educational integrity.

These differentiated elements demonstrate how European cities are evolving beyond basic greening, toward integrated, systemic, and child-centred solutions that recognize schoolyards as a microcosm of urban resilience, equity, and innovation.

8.3.6. Schoolyards as Urban Climate Infrastructure and Community Resources

A recurring insight from European best practices is the recognition of schoolyards as more than educational spaces. In many cases, they are being strategically reframed as neighbourhood-scale assets that can deliver climate, health, and equity benefits well beyond the school population. In dense or underserved urban areas, schoolyards often represent some of the only permeable, open, and potentially green spaces available—making them a critical yet underutilized resource in the effort to build climate-resilient and inclusive cities.

Cities like Paris, Barcelona, and Amsterdam have explicitly incorporated schoolyard transformation into their urban adaptation plans, targeting them as cooling islands, stormwater buffers, and biodiversity nodes within the urban fabric. Projects like OASIS and Refugis Climàtics went further by opening schoolyards to public use during non-school hours, turning them into accessible green areas for residents who often lack private gardens or parks—especially in lower-income districts. This approach directly advances goals of environmental justice, urban green equity, and public health resilience.

Furthermore, initiatives such as Opération Ré-Création in Brussels and AIS Amsterdam deliberately prioritized neighbourhood integration and intergenerational use, reinforcing the idea of schoolyards as shared civic infrastructure. These models illustrate how schoolyards can serve as key nodes in urban green-blue networks, complementing parks, plazas, and mobility corridors in multifaceted ways.

8.3.7. Strategic Selection Criteria for Schoolyard Transformation

Best practices also reveal that schoolyard transformation is most impactful when strategically prioritized, based on spatial, environmental, or social vulnerability. Several cases used data-driven selection methods to identify which schools and communities would benefit most from intervention.

Notably, Refugis Climàtics used climate risk mapping—assessing exposure to heat, lack of vegetation, building usage, and neighborhood vulnerability—to target 11 schools as pilots. Similarly, the OASIS project in Paris evaluated criteria such as demographic density, spatial accessibility, and urban heat exposure to ensure a representative and equity-oriented pilot group. In AIS Amsterdam, selection favoured schools in heat-stressed or low-income areas, while London's Climate Resilient Schools tailored interventions based on individual school climate adaptation plans (CAPs).

These selection strategies help schoolyard programs go beyond isolated improvements and instead serve as systematic tools for climate justice, urban regeneration, and child rights.

Table 8.3.7. Strategic Framing and Selection Criteria Across Best Practices

Best Practice	Urban Role Framing	Selection Criteria Used
Refugis Climàtics (Barcelona)	Climate shelters for public use, resilience in schools	Climate risk mapping (heat, air quality, vegetation)
OASIS (Paris)	Urban cooling islands, green justice in dense areas	Urban heat, demographic balance, accessibility
AIS Amsterdam	Public playgrounds in underserved neighbourhoods	Vulnerability, low-income areas, spatial equity
Opération Ré-Création (Brussels)	Shared green public space, educational biodiversity nodes	Schoolyard permeability, access, community engagement
Climate Resilient Schools (London)	Part of city climate infrastructure and learning network	Tailored CAPs using heat/flood risk, infrastructure audit
Cool Schools (EU-wide)	Schoolyards as drivers of urban transformation	City-based case selection focused on NbS implementation
EcoScholen (Antwerp)	Local climate adaptation strategy nodes	Funding open to all schools; growing alignment with policy
Groenblauwe Schoolpleinen (NL)	Green-blue infrastructure at regional scale	Not selection-based; accessible via criteria-based subsidies

9. Three Guiding Principles for Systemic Schoolyard Transformation

The comparative analysis of European best practices reveals that the transformation of schoolyards is no longer a marginal or isolated intervention. It is increasingly understood as a strategic, multi-dimensional tool for addressing complex urban challenges from climate change to child well-being and spatial inequity.
To translate these lessons into a practical and adaptable framework and toolkit, this chapter concludes with three guiding principles that frame the schoolyard as a resilient system, a developmental environment, and a public good. These principles offer a clear conceptual foundation for the design, implementation, and evaluation of future schoolyard interventions.

9.1. Climate Resilience

Schoolyards are increasingly recognized as critical assets in the urban climate infrastructure. Best practices demonstrate how schoolyards contribute to urban cooling, stormwater management, improved air quality, and biodiversity restoration. Cities like Paris and Barcelona are incorporating schoolyard redesign into their climate adaptation strategies, urban resilience frameworks, and public space policies, where schoolyards are viewed as climate shelters, public spaces that mitigate heat risk while providing shaded, accessible environments for learning and recreation.

At the local level, schoolyards are being transformed into climate-resilient micro-environments, cooling hotspots, water retention systems, biodiversity patches, and even renewable energy demonstration sites. These interventions vary in scale and complexity, but they share a commitment to Nature-based Solutions (NbS), environmental education, and public health resilience.

However, despite this progress, climate mitigation, including strategies related to carbon reduction, material circularity, and building energy use, remains underexplored in most cases. The focus remains mainly on outdoor spatial interventions, while building-related strategies are rarely integrated.

Moreover, while cities like Barcelona and London have launched parallel School Street initiatives to reclaim car-dominated access roads and improve air quality and safety around schools, these efforts are still not wide applied in other European contexts. The physical and functional thresholds between schools and their surrounding streetscapes often remain under-addressed, even though they are critical to achieving holistic climate resilience and child-friendly urban environments.

Furthermore, while the past decades have seen a growing focus on deep renovation of school buildings to improve energy performance, reduce operational costs, and meet carbon targets, the interdependence between indoor and outdoor environments is poorly explored. Research and practice still tend to isolate the school building from the surrounding open space, eventhough urban heat island effects, lack of shading, and surface reflectivity in schoolyards can significantly influence cooling demands in summer, while wind exposure and thermal loss across poorly designed outdoor areas can impact winter heating needs.

Bridging this research gap, by integrating outdoor microclimatic design with building performance strategies, represents a critical frontier in school-based climate adaptation. Again, the London CRS initiative remains a standout example, as it explicitly includes both spatial and architectural measures as part of a comprehensive climate response framework.

Integrating schoolyards, buildings, and surrounding urban space as a single, interrelated system is essential for maximizing resilience outcomes.

Linking Risk to Design: A Context-Based Climate Adaptation Framework
The design solutions adopted across European schoolyard transformations are closely tied to local climate and environmental risks. While some cities face increasing heat waves, others struggle with flooding or poor air quality. The table below synthesizes how different practices responded to specific risks with tailored design interventions, highlighting the value of context-based adaptation.

Table 9.1.1. Climate Risk and Design Responses in Best Practices

Hazard	Design Responses	Best Practices
Urban Heat	Tree canopy; shade structures; light surfaces; water play elements	OASIS (Paris); Refugis Climàtics; CRS London
Stormwater/Flooding	Bioswales; rain gardens; permeable paving; sponge schoolyards	Antwerp, Evergreen; Green-Blue NL; CRS London
Drought	Native plants; efficient irrigation; water reuse features	Amsterdam; Green-Blue NL; CRS London
Air Pollution	Vegetation buffers; green facades; sensors; zoning	Refugis Climàtics (Barcelona); CRS London
BiodiversityLoss	Pollinator gardens; edible planting; habitat zones	Brussels; Evergreen; Antwerp

9.1.2. Key Solutions to Address Climate Challenges

To organize and compare the typology and diversity of most common strategies, interventions are classified into three types of solutions commonly used in urban sustainability and environmental planning:

A. Green and Blue Nature-Based Solutions (NbS)
- These are vegetation- and water-based strategies inspired by ecological processes:
- Green NbS: tree planting, pollinator gardens, green roofs/walls, native vegetation
- Blue NbS: rain gardens, bioswales, infiltration ponds, water play areas

B. Grey Infrastructure Solutions
- Engineered materials or systems, often with a mitigation focus:
- De-paving and permeable paving
- Light-colored or reflective surfaces
- Shade structures (pergolas, tensile canopies)
- Stormwater tanks and cisterns

C. Hybrid or Integrated Solutions
- Blended ecological and technical approaches that support multi-functionality:
- Sponge schoolyards (combined water infiltration + play)
- Outdoor classrooms integrated with stormwater features
- Green roofs with educational signage
- Solar panels on shade structures

Based on the analysis of the interventions across best practices shown in Table 9.1.1.b , several strategies consistently are widely applied across different best practices:

- **De-paving and tree planting** are nearly universal features, appearing in almost all analysed best practices. These interventions are key strategies for increasing surface permeability, improving stormwater management, and providing shade and thermal comfort. Their simplicity, affordability, and high multifunctionality make them starting points in adaptation design.
- **Rain gardens, bioswales, and other stormwater management solutions** are particularly prioritized in areas facing high flood risk or urban water runoff challenges in the North-West Europe.
- **Hybrid educational–infrastructure models,** such as sponge yards, multifunctional gardens, and outdoor classrooms are increasingly recognized as high-impact approaches. These interventions have a dual role: they mitigate environmental risks while simultaneously enhancing learning experiences.
- **Grey solutions** such as engineered shading structures, reflective paving, and surface treatments are also gaining attention as critical complements to nature-based strategies. These interventions offer rapid and targeted benefits, particularly in addressing heat stress in high-exposure areas, and are often more feasible in densely built environments where tree planting or large-scale depaving may not be possible.

Table 9.1.2. Climate Adaptation and Mitigation Strategies by Best Practice

Solutions	Evergreen	Boston	Antwerp	Barcelona	Paris	Rdam	London	Bruxelles
Green NbS								
Tree planting / shade canopy	●	●	●	●	●	●	●	●
Native & pollinator gardens	●	●	●	●	●	●		
Green facades or walls				●				
Green roofs / living roofs							●	
Natural windbreaks / hedges	●		●				●	●
Blue NbS								
Rain gardens / bioswales	●	●	●		●	●	●	
Playful water management / infiltration				●		●		
Ponds or wetlands			●			●		
Water play / fountains / misters				●				
Grey solutions								
De-paving / permeable paving	●	●	●	●	●	●	●	●
Reflective or light-colored paving				●	●		●	
Shade structures (pergolas, etc.)		●		●	●		●	●
Rainwater harvesting / cisterns	●	●	●	●		●	●	
Tactical paving / surface painting	●	●			●	●		●
Hybrid solutions								
Sponge schoolyard / integrated systems	●					●	●	
Outdoor classrooms + ecological features	●	●	●		●	●	●	●
Solar panels (on shade structures)				●				

Figure 9.1.2 OASIS schoolyard, Paris, France

9.2. Child Health and Development

Across the best practices reviewed, child health and development emerge as central but variably addressed dimensions of schoolyard transformation. Both best practices and literature review show that schoolyards are not just recreational spaces, they are environments that influence physical activity, sensory stimulation, social interaction, emotional regulation, and learning. The design and use of outdoor space can either support or inhibit children's cognitive, emotional, physical, and social developmen, particularly when shaped by climate and environmental stressors such as heat, noise, or pollution.

Emerging models show that schoolyards designed for emotional regulation, cognitive stimulation, and inclusive play support both mental well-being and learning outcomes.

Table 9.2. Best Practices engaging with Child Health & Development. When tied to climate resilience, these goals are further amplified: reducing heat stress, improving air quality, and lowering stress levels can directly impact children's learning and health outcomes.

Best Practice	Focus on Child Helath and Development	Approach Depth	Methods Used
Community Schoolyards™ (USA)	Physical activity, nature access, equity	High – long-term studies	User behavior monitoring, gender equity analysis
Evergreen Climate Ready (Canada)	Play, cognition, emotional well-being	High – integrated design logic	Sponge design, sensory play, learning zones
Refugis Climàtics (Barcelona)	Heat stress, mental well-being	High – monitored impacts	Climate and air quality sensors, educational integration
OASIS (Paris)	Physical and mental health	Medium – linked to resilience	Outdoor learning, biodiversity, inclusive design
Opération Ré-Création (Brussels)	Movement, mixed play, emotional health	Medium – design-oriented	Mounds, tunnels, quiet zones, sensory variety
Green Schoolyards America (USA)	Sensory and developmental diversity	High – research-supported	Tree canopy equity, outdoor classrooms
Cool Schools (EU-wide)	Well-being, co-benefits focus	High – research still in progress	NbS impact studies on learning and health
Blauw Groen Vlaanderen (Belgium)	General well-being and physical activity	Light – embedded in goals	Biodiverse zones, natural materials
AIS Amsterdam	Play and cognitive development	Medium	Multifunctional zoning.

9.2.1. Zoning Approach: Active – Semi-Active – Quiet zones

A recurring design strategy in child-centered schoolyards is the division into activity-based zones, typically categorized as Active, Semi-Active, and Quiet zones as seen in Table 9.1.2.b.

Table 9.2.1.a Zoning approach: Active – Semi-Active – Quiet

Zone	Developmental Benefits
Active	Gross motor skills, risk-taking, social interaction
Semi-active	Cooperative play, sensory exploration, creativity, environmental engagement
Quite	Emotional regulation, self-reflection, calm retreat, focused learning

This approach reflects core principles in developmental psychology and inclusive design by offering multiple modes of engagement and allowing children to choose what they need at any given time: physically, socially, or emotionally. However, despite this, neurodiversity and adolescent needs remain under-addressed in many current models. Projects like Refugis Climàtics, Opération Ré-Création, and Evergreen Climate Ready explicitly use this zoning structure, while others, such as AIS Amsterdam and Groenblauwe Schoolpleinen, apply it implicitly through multifunctional layouts and sensory-diverse environments (Table 9.1.2.c).

Table 9.2.1.b Best practices using zoning strategy

Best Practice	Zoning used	Application principle
Refugis Climàtics (Barcelona)	Explicit	Structured zoning into active, semi-active, and quiet areas + sensory features
Opération Ré-Création (Brussels)	Explicit	Includes climbing/play (active), nature play and tunnels (semi-active), sensory/rest zones (quiet)
OASIS (Paris)	Implicit	Designs include diverse play, shaded rest zones, and outdoor classrooms
Evergreen Climate Ready (Canada)	Explicit	Sponge yard model includes hill slides (active), sand/water play (semi-active), and nature nooks (quiet)
AIS Amsterdam	Implicit	Multifunctional layouts encourage mixed-use zoning, including public/quiet use
Groenblauwe Schoolpleinen (NL)	Principle-based	Tools and 8 principles promote sensory-rich and activity-diverse environments
Blauw Groen Vlaanderen (Belgium)	Principle-based	Encourages diverse play types and vegetation for calming and stimulating experiences
Community Schoolyards™ (USA)	Implicit	Unstructured, mixed-activity zones with shaded, open, and garden spaces

Why Does This Approach Matters?

The Active / Semi-active / Quiet zoning model is more than a design technique, it's a child-centered planning tool grounded in developmental psychology, inclusion, and self-regulation theory that:

- Encourages autonomy and agency in how children engage with space
- Supports learning-readiness by offering emotional reset spaces
- Supports social diversity, welcoming introverted, neurodivergent, or overstimulated children
- Can guide time-of-day programming, e.g., morning learning in quiet zones, afternoon play in active zones

9.3. Promotion of Shared Use

Many best practices go beyond school hours and boundaries, recognizing that schoolyards can function as shared community infrastructure. In dense or underserved areas, they are often among the only available green, permeable, or play spaces. When opened to the public, schoolyards contribute to urban equity, intergenerational interaction, and civic identity.

- Cities leading this approach include:
- Amsterdam (AIS) and Paris (OASIS): formalizing schoolyards as semi-public green spaces
- Community Schoolyards™ (USA): opening grounds after school and on weekends
- Brussels: inviting the community to co-create and activate the space through tactical urbanism and participatory play

Designs that promote unstructured movement, cooperative play, and flexible use help foster physical activity, socialization, and community ownership, especially for children who might otherwise be excluded.

9.4. Strategic Gaps and Underexplored Topics

Despite the progress, there are several underexplored dimensions in current best practices:

- **Climate mitigation:** Few projects address energy use, materials sourcing, or carbon footprint.
- **Interrelation between school building and yard:** Often studied separately, only CRS addresses this aspect.
- **Older student groups:** Most designs cater to younger children; adolescents are often underserved.
- **Neurodiversity and inclusive play**: While inclusivity is referenced, few projects are designed for neurodivergent children or sensory-sensitive users.
- **Circularity and material reuse:** Only isolated examples mention recycled materials or low-carbon sourcing.

9.5. From Best Practices to Framework and Toolkit Development

The insights drawn from the best practices chapter, combined with the theoretical foundations laid out in the Part II of this thesis, with the literature review on climate resilience, health and well-being, child development, biotope loss, physical inactivity, ansd spatial inequity serve as the key ingredients for the development of the REACTIVE Framework and Toolkit.

REACTIVE Framework is as a practical, evidence-based guide and toolkit that supports schoolyard transformation offering:

- a clear methodological structure,
- a suite of design solutions and strategies,
- a vision of integrated, systemic change.

Table 9.5. Visual summary table mapping eight common schoolyard design elements against the five lenses–Climate, Health, Activity, Development, and Spatial Inequity/Accessibility–highlighting co-benefits (++/+) and potential conflicts (-/o). Each row also includes concise notes for design caution or optimization.

Solution	Climate Resilience	Promoting Activity	Spatial Inequity	Child Development	Health	Notes
Trees & Vegetation	++ Cooling, shade	+ Climb/hide	+ Must be distributed	++ Sensory/ cog.	++ Stress reduction	*Maintenance critical; root/ soil volume*
Permeable Surfaces	++ Infiltration	o Surface not activity	+ Cost moderate	+ Stewardship	+ Less flooding	*Needs sub-base design; reduces runoff*
Play Mounds / Topography	+ Airflow disrupt	++ Climb/run	+ Needs space	++ Risk-taking	+ Balance heat	*Watch slopes for ADA; combine with shade*
Shaded Rest Zones	++ Cooling	+ Low-intensity	+ Can be modular	+ Self-reg.	++ Restorative	*Combine with drinking water*
Movement Loops & Trails	+ Shaded movement	++ Dynamic movement	+ Path continuity	++ Motor skills	++ Cardiovascular	*Ensure loops cross diverse zones*
Habitat Patches / NbS	++ Cooling, evapotransp.	+ Nature play	+ Low-cost patches	++ Biodiversity literacy	++ Mental restoration	*Use native species; involve students*
Open Multipurpose Field	+ Potential heat	++ Ball games	- Often dominates boys	+ Team play	+ Physical, but sun	*Mark zones to avoid exclusion*
Rain Garden / Water Feature	++ Cooling, evapotransp.	+ Interactive water	+ Needs maintenance plan	++ Sensory play	+ Restorative sounds	*Safety around water; seasonal variation*

Table 9.5. Best practices synthesis comparing leading schoolyard initiatives across EU highlighting climate-health challenges, strategies, co-design practices, policy integration, and transferability.

Best Practice	Country / City	Type of Best Practice	Key Climate & Health Challenges Addressed	Strategis Focus & Objectives	Notable Design or Policy Strategies	Co-design & Participation	Integration into Urban Policies	Transferibility Potential
OASIS	France / Paris	Transformation	Urban heat, spatial inequity, inactivity	Climate shelter, equity, open public space	NbS, permeable paving, shade, public access	Yes – with students and school staff	Part of Paris Climate Plan (2050 target)	High – phased city-led model with evaluation
Refugis Climàtics	Spain / Barcelona	Transformation.	Heat, air quality, socio-spatial vulnerability	Climate adaptation, mental health, air quality	Sensors, NbS, indoor-outdoor climate monitoring	Yes – living lab model	Integrated in city health & climate strategy	High – data-driven risk selection and sensor innovation
Opération Ré-Création	Belgium / Brussels	Transformation + Education	Lack of play, biodiversity, educational gaps	Biodiversity learning, inclusive play, access	Tactical urbanism, co-design games, curriculum integration	Yes – extensive workshops and tools	Supported by Brussels Capital Region	Medium – needs strong coordination and education focus
AIS Amsterdam	Netherlands / Amsterdam	Transformation + Policy	Heat, inequity, inactivity	Public playgrounds, child-friendly design, inclusion	Open schoolyards, equity-driven selection	Yes – with local communities	Coalition agreement and urban plan	High – strategic alignment and clear criteria
Climate Resilient Schools	UK / London	Transformation + Building	Heat, flooding, energy use	Whole-campus climate adaptation	CAPs, cool roofs, ventilation, water saving	Yes – child-centered education tools	Part of London Resilience Strategy	High – whole-system model, scalable with policy support
EcoScholen	Belgium / Antwerp	Funding / Programmatic	Stormwater, biodiversity, educational integration	Environmental education, resilient schoolyards	Subsidies, quality criteria, curricular links	Yes – school-driven applications	Supported by Antwerp education & environment depts	High – based on clear principles and support tools
MICOS	Spain / Madrid	Transformation + Street Redesign	Heat, air pollution, safety, access	School and street redesign, safe thresholds	Integrated street–yard interventions, trees, depaving	Yes – participatory urbanism	Madrid environmental and education integration	Medium – street integration depends on municipal authority
Blauw Groen Vlaanderen	Belgium / Flanders Region	Funding / Framework	Stormwater, heat, access to nature	Green-blue networks, pedagogical integration	8 Design Principles, funding + coaching	Yes – recommended in program design	Linked to Flemish spatial and environmental policies	High – principles and subsidies replicable
Groenblauw Schoolplein	Netherlands / Various Cities	Funding / Transformation	Heat, flooding, biodiversity	Green-blue climate adaptation at school scale	Subsidy scheme, NbS, biodiversity, outdoor learning	Yes – flexible participation options	Supported by regional and local governments	High – toolkit and evaluation built-in
Cool Schools	EU-level	Research + Policy	Urban heat, socio-environmental inequity	Pan-European transfer of schoolyard NbS	EU case studies, data-driven pilots, upscaling methods	Yes – pilot cities engaged communities	Linked to EU adaptation strategy and local plans	High – framework explicitly supports scaling and learning

PART IV -
REACTIVE Framework methodology & development

This part of the thesis outlines the development process of the REACTIVE Framework. It presents the methodological approach, analytical logic, and design rationale that guided the translation of scientific knowledge into an operational framework and toolkit. By integrating interdisciplinary research, best practices, and systems thinking, Part IV demonstrates how climate, health, and child development priorities were synthesized into actionable tools, indicators, and strategies for schoolyard transformation.

10. Methodology and Research Design

The development of the REACTIVE Framework was grounded in a mixed-methods and interdisciplinary research approach. The process combined theoretical research, systems thinking, and practice-based design methodologies to create an evidence-based and operational framework and toolkit.

The methodology integrates the following key elements:

- **Literature review (Part I,II)**: A structured review of scientific literature in the fields of climate change, child health and development, environmental psychology, urban planning, physical activity, spatial inequity, and schoolyard design provided the theoretical foundation of the framework. This phase allowed for the identification of key health determinants, spatial dynamics, and developmental needs of children in urban environments and respective indicators that feed into the Audit tools (presented in Part V).
- **Best Practices and Toolkit review (Part III):** A comparative analysis of over 40 international schoolyard transformation projects, frameworks, and guidelines revealed methodological approaches and gaps, innovative approaches, success factors, key barriers, and practical strategies. This analysis informed the structure, modularity, and usability of the REACTIVE Toolkit and the methodological development.
- **Participation in research projects:** Insights were drawn as well from prior applied research experiences in the frame of my fellowship, such as the FIABA, Raggio Verde, and Erasmus+ U-CARE project. These experiences include research, site visits, user testing sessions, and co-design workshops with citizens and students contributing to the methodological development, definition and development of indicators, co-design methods, and spatial strategies.
- **Previous professional experiences:** The Symbiosis in Development (SiD) framework supported this research from the outset, embedding a systems-thinking dimension into both the conceptual framing and the development of the REACTIVE framework. It provided a foundation for understanding schoolyards as integral parts of larger urban ecosystems, where climate risks, socio-spatial vulnerabilities, behavioral dynamics, and institutional capacities interact. Beyond shaping the theoretical lens, the SiD framework also inspired the design of the methodology and the process itself—guiding the integration of dynamic feedback loops across design, health, and environmental systems. This systemic perspective ensured that the research remained holistic, adaptive, and grounded in real-world complexity.

The combination of these methods made sure the framework was both scientifically sound and practica, able to respond to real-world needs and adapt to different contexts. In addition to literature and best practice review, the development of the overall research was enriched by active participation in applied research projects. These experiences offered opportunities for field testing, stakeholder engagement, and methodological development. The following table 10. summarizes key contributions of each project.

10.1. Construction of the Analytical Framework

The construction of the REACTIVE analytical framework was directly informed by the literature review presented in Parts I and II and the analysis of the Best Practices presented in Part III. Starting from the overarching challenges of climate change and child health in urban environments, the literature identified a set of interrelated stressors and spatial determinants that disproportionately affect vulnerable groups, particularly children.

To translate climate and environmental challenges into actionable spatial design strategies, the REACTIVE Framework adopts a risk-based approach grounded in the IPCC Risk Framework. This risk logic (risk = hazard × exposure × vulnerability) provides the methodological backbone for systematically analysing climate- and environment-related threats and for understanding how spatial conditions shape children's exposure and vulnerability, thereby translating risk into design priorities for school-related environments.

Within REACTIVE, risk is understood as the potential for adverse consequences for children's health, well-being, and development, arising from the interaction between (i) climate- and environment-related hazards and stressors, (ii) patterns of exposure shaped by space and daily routines, and (iii) age-specific vulnerability.

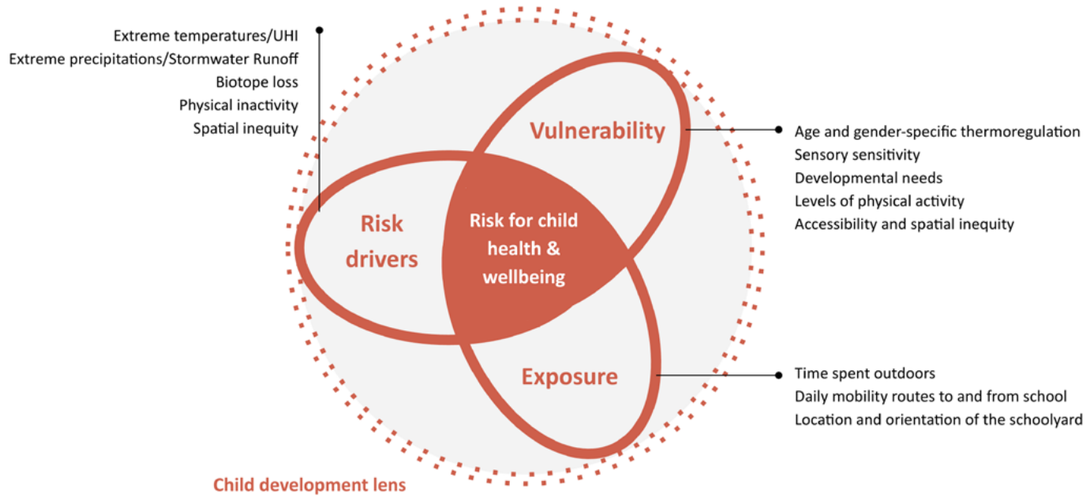


Figure 10.1 Adapted IPCC Risk Framework for school-related environments.

Based on these insights, the research first mapped risk drivers as the set of phenomena and spatial determinants that can generate or amplify risk in school-related environments. This mapping informed a core set of determinant themes, which were studied in detail and structured into five main pillars: climate resilience (urban heat and stormwater runoff), biotope loss, physical (in)activity, spatial inequity, and child development. Figure 10.1 illustrates this logic by positioning "risk for child health & wellbeing" at the intersection of risk drivers (what can cause harm), exposure (how children come into contact with it), and vulnerability (why children are susceptible), with child development acting as an age-sensitive interpretive lens.

In this context, health served as both the starting point and the ultimate goal of the framework. The initial step involved identifying the factors that influence children's health and development, both negatively (risk drivers) and positively (protective spatial qualities), in school-related settings (Part I and Part II). From this, design-relevant domains were defined and linked to health implications, and the framework explicitly explored synergies and trade-offs between domains (Part II), to avoid solving one issue at the expense of another.
Table 10.1.a summarizes the determinant themes (five pillars) and the primary health and development outcomes they influence.

Table 10.1.a Set of determinant themes that influence health outcomes (from literature review presented in Part II).

Determinant themes	Health Outcomes
Heat (UHI)	Heat stress, cognitive fatigue, safety, usability
Stormwater Runoff	Hygiene, flood risk, mosquito/disease risk
Biotope Loss	Immune health, emotional regulation, learning
Phyiscial (in)Activity	Motor development, physical health, socialization
Child Development	Cognitive development, emotional regulation
Spatiel Inequity	Universal access to all developmental benefits

Considering that children are the main target group of the research, child development was introduced as a cross-cutting design lens. Although child development is embedded in the WHO definition of health, it is often marginalised in spatial and architectural practice. Moreover, the stressors addressed in this thesis—urban heat, stormwater risk, biotope loss, limited activity opportunities, and spatial inequity—undermine not only immediate health outcomes but also physical, cognitive, social, and emotional development. Recognising this gap, the framework positions child development not only as an outcome, but as a driver that determines which spatial and environmental qualities are most essential.

These conceptual foundations informed the analytical structure of the framework, organised as: Outcomes K Determinants K Indicators. Outcomes refer to physical and mental health, as well as child development (cognitive, motor, emotional, and social domains). Determinants include environmental and behavioural conditions that shape risk and protection (e.g., thermal comfort, water safety, biotope quality, activity affordances, accessibility, and inclusion). Indicators are measurable parameters used to evaluate these determinants (e.g., % shaded area, permeability/infiltration capacity, biodiversity proxies, m² of play area per child, noise level in dB).

To allow for spatial application and integration with planning and design processes, the framework is structured across three interrelated spatial scales:

- **Macro**: Neighborhood-level systems, access, and environmental exposure
- **Meso**: School premises and thresholds
- **Micro**: Schoolyard design and child experience

A matrix linking outcomes, determinants, and indicators across these three scales forms the foundation for the Toolkit's audits, tools, and design guidelines.

Design strategies are treated as the operational "response" layer: they intervene on determinants to reduce exposure and vulnerability and to shift risk outcomes. Finally, strategies from each lens were mapped and cross-compared in a Co-benefit Strategy Matrix in Part II to identify recurring strategy families with the highest multi-lens synergies and to make typical trade-offs/risks explicit. This synthesis step directly informed the final set of strategies and solutions included in the REACTIVE Toolkit.

Table 10.1.c Outcome Matrix showing how each theme (determinant) influences specific goals/outcomes

Determinant	Physical Health	Mental Heatlh	Cognitive / Emotional Development	Motor Development
Thermal Comfort	●	●	●	●
Biotope	● (immune)	●	●	-
Physical Activity	●	● (stress release)	● (focus, self-control)	●
Sensory & Learning Stimuli	-	●	●	-
Equity & Inclusion	●	●	●	●

Following this approach, based on the risk drivers identified in Part I and the recurring themes highlighted in the literature review and analysed in Part II, the framework introduces a five-lens approach that frames the core dimensions to consider when analysing and designing school-related environments. Together with the three-scale spatial framework (macro, meso, micro), they form the analytical backbone of this research and of the framework. Both the lenses and the three-scale spatial framework are embedded throughout the REACTIVE Framework and Toolkit, informing the selection of indicators, the audit structure, and the design strategies.

10.1.1. Five Thematic Lenses

Five thematic lenses—urban heat, stormwater and flooding, biotope loss, physical inactivity, and spatial inequity—represent cross-cutting themes that significantly influence children's health, development, and daily experiences. They are valuable for assessing the current conditions of school-related environments, guiding the design of interventions, and evaluating the outcomes of implemented solutions.

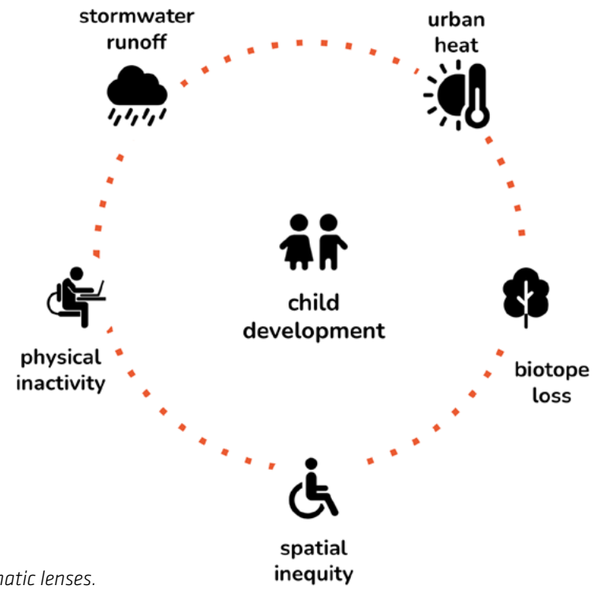


Figure 10.1.1 Five thematic lenses.

>>> The five lenses are not isolated categories but interdependent cross-cutting themes that interact spatially and systemically.

1. **Child Development** is identified as the primary interpretive lens through which all design choices are made. Developmental stages define children's cognitive, emotional, sensory, and motor needs, shaping how they interact with and benefit from the built environment. A child development perspective must be embedded in every stage of the design process—from the spatial layout and zoning of functions, to the selection of materials, affordances, and sensory elements. This lens ensures that environments not only protect children's health but also actively support learning, socialization, emotional regulation, and physical growth.

2. **Climate Resilience** is identified as one of the primary hazards for children's health and well-being. Schoolyards must be able to not only respond to extreme weather events such as extreme heat and heavy rainfall, but also integrate adaptation strategies into their design. These features include shading (natural or artificial), permeable surfaces, and rich, layered vegetation, which together ensure optimal outdoor thermal comfort, reduce climate-related risks, and maintain the usability of outdoor spaces throughout the school year.

3. **Biotope Recovery** is a key strategy for improving the ecological quality of schoolyards, directly influencing biodiversity, sensory stimulation, and children's mental restoration. Increasing natural habitats through Nature-based Solutions (NbS) with layered vegetation, pollinator-friendly planting, or green corridors not only supports urban biodiversity but also provides developmental benefits. These include opportunities for nature play, emotional regulation, and cognitive engagement, while simultaneously contributing to climate adaptation through shading, evapotranspiration, and stormwater regulation.

4. **Physical activity** should be embedded across all aspects of urban design, not just confined to localized facilities like playgrounds or sports fields. To reduce obesity risks and promote active lifestyles, cities must create informal, everyday opportunities for movement from walking to school, playing in the schoolyard, or engaging in playful way with benches, walls, or paths. Design must offer both structured and unstructured movement, actively and passively stimulating physical engagement. One of the kay aspects to also address are disparities in activity linked to gender, age, and ability.

5. **Spatial inequity** means guaranteeing all children, regardless of age, ability, gender, or socioeconomic background to have fair access to healthy, green, and climate-protected school environments. Accessibility must be understood in a holistic sense: not only as the removal of physical barriers, but also as the creating of safe, comfortable, nature rich, and socially inclusive spaces. Furthermore, design should recognize different needs and preferences within the school community.

10.1.2. Three-scale spatial framework

A child's experience doesn't start at the school gate– it begins at home and the journey to school. The quality, safety, and inclusivity of public spaces encountered on the journey to school significantly shape their health, autonomy, and emotional well-being. Sidewalks, crossings, green corridors, and neighborhood parks are not merely neutral backgrounds, but rather active determinants of their daily lives and health.

Moreover, the school, including the building and its outdoor spaces, is part of a larger system of buildings, spaces, and institutions. To fully understand how school environments can promote child health, development, and climate resilience, it is essential to consider this spatial complexity. Therefore, each of the five previously introduced thematic lenses (child development, climate resilience, biotope loss, physical activity, and spatial inequity) must be applied across three interrelated spatial scales:

1. **Macro scale –** Urban Context: The broader neighborhood and environmental context in which the school is located, including exposure to urban heat, access to green space, air quality, and the walkability or bikeability of routes to school.
2. **Meso scale –** School Premises: The school grounds beyond the yard, including the perimeter, entrances, parking/drop-off areas, transition spaces, and relationships between built volumes and open space.
3. **Micro scale –** Schoolyard: The detailed configuration of the yard itself – its affordances, play structures, vegetation, surface materials, shading, and sensory elements that directly shape children's experiences.

By applying each design lens at multiple scales, the research aims to bridge the gap between strategic planning and tactical design, connecting systemic urban challenges with concrete interventions that support health, equity, and ecological performance.

The proposed three-scale framework is not only essential for addressing climate and health-related risks at multiple levels, but it is also instrumental in revealing the strategic role school-related environments can play within the neighborhood fabric, especially in dense urban settings.

10.2. Toolkit Logic & Structure

The REACTIVE Toolkit operationalizes the analytical framework through a set of structured, user-oriented tools and strategies. Its logic is based on modularity, simplicity, and flexibility to serve a range of users (municipalities, designers, school communities) and different scopes and scales of interventions.

The design of resilient, health-promoting school environments requires an integrated approach that connects climate adaptation, child development, and urban equity. The toolkit was developed to bridge the gap between scientific research and practical implementation, offering concrete support to those involved in transforming schoolyards and their surroundings. Rather than being a fixed guide, it functions as a flexible framework, adaptable to different local contexts, stakeholder capacities, and project scales.

The structure and tools have been carefully designed to respond to four key operational needs that emerged through research and fieldwork:

- **User Differentiation:** The toolkit supports different actors through tailored entry points and roles.
- **Scalability:** Tools can be applied to single schools, networks, or city-wide programs.
- **Visual Communication:** Diagrams, checklists, and flowcharts make scientific content more accessible.
- **Integration of Co-Design:** Child-centered participatory tools are embedded as core components, not add-ons.

Furthermore, the toolkit is structured to provide users with a comprehensive yet flexible set of resources that support the full process of diagnosing, designing, evaluating, and co-creating climate-resilient, healthy, and inclusive school environments. Each component responds to a specific phase of the transformation process, from initial assessment to design implementation and user engagement. Together, these tools ensure that interventions are evidence-based, context-sensitive, and aligned with children's developmental and environmental needs. Each tool is derived from the evidence synthesized in Parts II and III and aligned with the determinant-indicator structure introduced in the analytical framework.

Toolkit Components:

- **REACTIVE Audit:** A three-scale diagnostic tool assessing climate risks, environmental quality, and developmental needs.
- **Risk driver cards**
- **REACTIVE Design Guidelines:** Spatial principles organized by key design levers and cross-cutting criteria.
- **REACTIVE Co-Design Tools:** Participatory materials for involving users in planning.

10.3. Development of the REACTIVE Audit

An environmental quality audit for child-centered environments, such as schoolyards, school premises, and the surrounding public spaces that shape the daily school experience, assesses how well these places support children's health, safety, development, and well-being. These environments include not only the physical schoolyard, but also routes to school, waiting areas, and nearby open spaces, all of which influence children's daily exposure to environmental risks or benefits.

While not yet standardized like an energy audit, this type of audit are an emerging and important tools in inclusive, health-supportive urban and school design. It helps identify where risks exist, where improvements are needed, and how interventions can create environments that are more resilient, inclusive, active, and developmentally supportive.

Objectives

- Identify environmental, spatial, and social risks in child-centered environments
- Highlight vulnerabilities and opportunities for improvement across key dimensions
- Connect physical space conditions to children's health, development, and equity outcomes
- Support evidence-based design, retrofitting, or policy decisions for transformation

Table 10.3. Overview of key dimensions, respective indicators and relevance.

Lens	Indicators	Tools / Methods	Relevance for children
Urban Heat Risk	Surface & air temperatures; Shading & vegetation coverage; Albedo of materials	ENVI-met; Thermal imaging; Visual audits	Heat stress, fatigue, reduced play, lower concentration
Stormwater and Drainage	Permeable vs. sealed surfaces; Drainage flow; Flood-prone areas	Runoff coefficient; On-site inspections; Simulation tools	Injury risk, standing water, loss of space usability
Biodiversity and Sensory Stimulation	Presence of natural elements; Variety of vegetation; Presence of pollinators or wildlife	NDVI; Observation checklists	Supports emotional regulation, learning, and sensory development
Physical Activity and Play	Space for free and structured play; Movement pathways; Terrain variation and affordances	Observational studies; Layout analysis	Encourages motor skills, socialization, physical health, reduces obesity
Spatial Inequity and Accessibility	Distribution of shade, play, and rest zones; Inclusive design features; Maintenance levels	Spatial mapping; Stakeholder surveys	Ensures fair access, prevents exclusion, supports all users

10.3.1. Three-scale framework applied to Audit

The framework, and consequently the audit, follows a three-scale approach. From the broader urban surroundings (macro scale), to the immediate school entrance and building-schoolyard interface (meso scale), down to the detailed layout and feel of the yard (micro scale), each level presents different challenges and opportunities.

Table 10.3.1. Three-scale framework

Scale	Focus	Themes
Macro	Urban and environmental context	Climate and environment-related hazards, connectivity, access, neighborhood climate risks, mobility
Meso	School + Schoolyard system	Layout, green/grey balance, building-outdoor relationship
Micro	Human-scale experience	Shade, comfort, materials, biodiversity, social interaction

Following a short description of each scale, including a table that explains the logic behind the audit structure, outlining how the three-scale approach informs the selection of indicators and the framing of key questions. It helps clarify what each scale aims to assess and what kind of outcomes the audit is designed to support identifying risks, highlighting opportunities, and setting priorities for meaningful transformation.

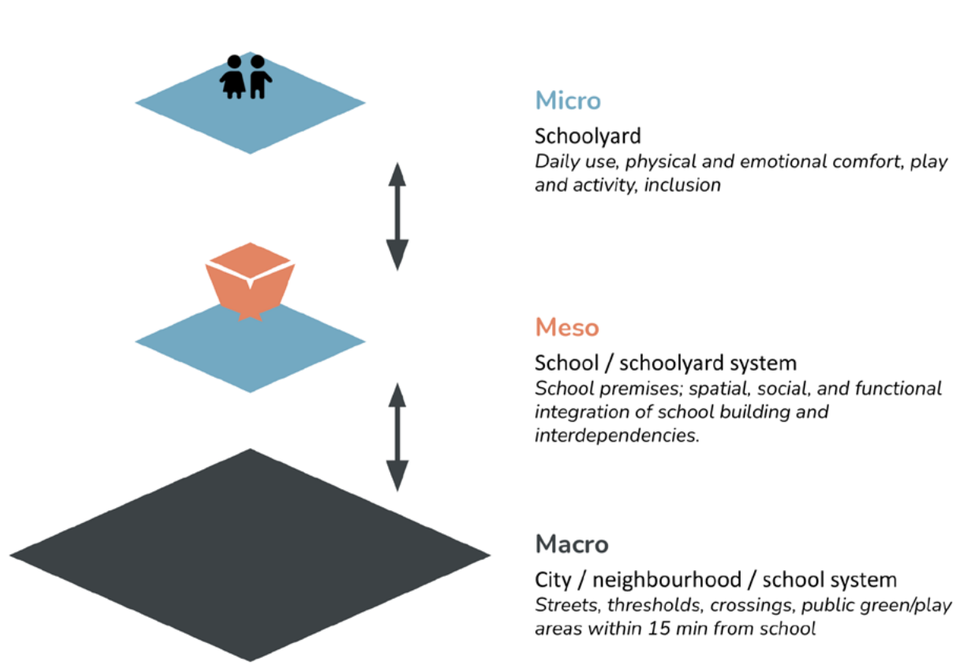


Figure 10.3.1 REACTIVE three-scales

Macro Scale: Setting the context

This scale explores which broader environmental and social conditions shape children's exposure to risks, access to developmental resources, and their ability to move, grow, and thrive in daily life. The aim is to define the larger environmental and social conditions surrounding the school environment. It captures urban and neighborhood-level preconditions that shape exposure to risks or access to health-supporting opportunities. This includes factors like mobility infrastructure, green network connectivity, environmental quality, and socio-demographic patterns. These elements are usually outside the immediate control of school designers but have a critical influence on health, development, and resilience potential.

To support analysis and planning at this level, the following table outlines key guiding questions and the overall objective of the macro-scale assessment.

Table 10.3.1.a Overview of key guiding questions and overall aim at the macro scale.

Lens	Sub-questions	Overall aim
UHI	Are children exposed to high ambient temperatures and heat stress on their way to school? Does the neighbourhood offer shade or thermal refuge?	Evaluate urban heat exposure and define baseline thermal stress and canopy coverage on the route to school. Background
Stormwater Run-off	Is the school located in a flood-prone area that compromises access or safety? Do pupils face disruptions on the journey during rain events?	Evaluate hydrological characteristic – regional flood risks, stormwater runoff index
Biotope Loss	Do children have access to biodiverse green spaces nearby? Is the school connected to ecological networks?	Evaluate ecological connection to green corridors, nature access
Physical Inactivity	Are walk- and bike paths safe, pleasant, and direct enough to support active commuting?	Evaluate active mobility opportunities – walk/bike access to school
Spatial Inequity	Are environmental benefits and risks (green, shade, pollution, noise) distributed fairly along pedestrian routes, crossings, and public-transport stops/stations that pupils use? How accessible and barrier-free are those paths and nodes?	Evaluate Environmental/social quality of the pedestrian network
Child Development	Does the surrounding environment support autonomy, exploration, and equitable access to cultural or natural resources?	Preconditions – autonomy, access, supportive environment

Meso scale: The School as a System

Meso Scale (School street, entrance zone, building–yard interface) focuses on the school and yard as an integrated system by exploring how the school-street frontage, entrance design, and building envelope mediate environmental risks, protect health, and enable positive indoor–outdoor experiences for children. Its aim is to shape systemic conditions through design and layout.

To support analysis and planning at this level, the following table outlines key guiding questions and the overall objective of the meso-scale assessment.

Table 10.3.1.b Overview of key guiding questions and overall aim at the meso scale.

Lens	Sub-questions	Overall aim
UHI	Do entrance plazas and façades provide shade and use high-albedo / cool materials? Do green roofs or facades reduce heat gain and improve outdoor microclimate?	Systemic buffering – vegetation and material choices mitigate heat
Stormwater Run-off	Are permeable surfaces, rain gardens, or trench drains integrated into the school's frontage and roof drainage?	Drainage logic – surface permeability, retention systems
Biotope Loss	Do vegetated façades, planter balconies, or green roofs add habitat and connect to yard greenery?	Systemic ecological quality – diversity of species and planting in yard
Physical Inactivity	Does the entrance forecourt invite movement (ramps, steps, micro-topography) and support active arrival rituals?	Movement-oriented layout – circulation loops, affordance zones
Spatial Inequity	Is the main access barrier-free? Do all age and ability groups enter through equally dignified, comfortable routes?	Distribution within school – equitable zoning and access
Child Development	Does the building envelope visually connect classrooms with greenery and play? Do thresholds encourage curiosity (views, loose-part storage, sheltered outdoor learning niches)?	Systemic enablers – layout and scheduling that support development
Comfort	How does façade performance (insulation, glazing ratio, shading devices) influence indoor thermal quality during outdoor heat events? Do overhangs buffer rain and glare at entrances?	Design-mediated control – orientation, shade, shelter, material logic

Micro scale: Shaping Everyday Experience

Micro Scale (the schoolyard) addresses child-level, human-scale interactions with the space. It reflects the immediate, sensory, and behavioral experience: what children feel, do, see, and hear. This includes temperature sensations, availability of play and rest features, sensory stimuli, and exposure to discomfort or barriers. Micro-scale insights are essential for capturing the actual lived experience, which may differ from design intentions.

To support analysis and planning at this level, the following table outlines key guiding questions and the overall objective of the micro-scale assessment.

Table 10.3.1.c Overview of key guiding questions and overall aim at the micro scale.

Lens	Sub-questions	Overall aim
UHI	Is there adequate instantaneous shade, cool surfacing and evapotranspirative greenery across play zones?	Felt experience – shade, surface temperatures, comfort during use
Stormwater Run-off	Is the green-to-grey ratio high enough to absorb rain? Are bioswales or rain-play features keeping surfaces usable?	Impact on usability – pooling, safety, disrupted use
Biotope Loss	Do children directly engage with layered vegetation, pollinators, seasonal change and nature-play elements?	Sensory biodiversity – textures, sounds, smells experienced directly
Physical Inactivity	Do layout, materials, and equipment invite diverse movement (running loops, climbing, balance, informal sport)?	Active moments – observed use of play and movement features
Spatial Inequity	Can every child reach shade, rest spots, and varied play types, regardless of mobility, age, or gender?	User-level fairness – inclusive access to shade, comfort, play
Child Development	Are there rich affordances for cognitive, social, emotional, and motor growth, such as loose parts, quiet nooks, role-play corners, and sensory gardens?	Direct experiences – what a child can do, feel, and learn
Comfort	What are the real-time sensations of temperature, noise, air quality and crowding during peak use?	Evaluate overall sensory comfort

10.4. REACTIVE Indicators

The REACTIVE indicators are designed to translate complex concepts, such as climate resilience, health promotion, and developmental quality, into operational and context-sensitive metrics. This system of indicators supports both assessment and post-intervention evaluation, thereby bridging the gap between research and practice.

The development of indicators for the REACTIVE framework was grounded in a rigorous, multi-step process that combined scientific validity with practical applicability. The goal was to create a set of metrics capable of capturing the complex interplay between spatial design, hazards, and child health and development. The process drew from international standards, existing best practices, and a translational approach that connects scientific evidence to measurable, spatially relevant criteria. The steps outlined below illustrate how the indicators were selected, adapted, and structured to align with the five REACTIVE lenses and the three spatial scales of analysis.

Indicator development steps:

1. **Source Mapping:** Key international frameworks were reviewed, including:
   - WHO Urban Health Initiative and air/noise/thermal thresholds
     - IPCC AR6 (2023) urban risk dimensions (hazard–exposure–vulnerability)
     - IUCN and EU biodiversity standards
     - UNICEF Child Development indicators and rights-based frameworks
     - ENVI-met thermal comfort outputs (UTCI, MRT, evapotranspiration)
2. **Best Practices Extraction**: Metrics used in existing toolkits (e.g., UrbanCare Methodology, Healthy Streets Index, etc.) were compared.
3. **Scientific-to-Spatial Translation:** Abstract determinants (e.g., "opportunities for play") were translated into spatial metrics (e.g., "m² of play space per child", "variety of affordances", etc.).
4. **Categorization by Lenses and Scales**: Indicators were organized according to the REACTIVE Five Pillars and Three Spatial Scales, ensuring coherence across the audit framework (Annex, pg. 236-245).

Furthermore, to effectively evaluate school environments through the REACTIVE framework, a mix of quantitative and qualitative indicators is used. This combined approach allows for a more holistic understanding of spatial and environmental performance, capturing both measurable physical attributes and experiential, user-centered qualities. Quantitative indicators provide objective data for comparison and benchmarking, while qualitative or observational indicators help assess aspects such as inclusivity, sensory richness, and real-world usability, particularly important when evaluating environments from a child-centered perspective.

Indicator Types:

- **Quantitative:** % shaded area, vegetation cover, AQI, decibel levels, surface temperature.
- **Qualitative/Observational:** Sensory diversity, accessibility, usability for children of different abilities.

Following, the complete set of indicators used to develop the REACTIVE Audit, organized according to the three spatial scales (macro, meso, micro) and aligned with the six analytical lenses: Urban Heat Island (UHI), Stormwater Run-off, Biotope Loss, Physical Inactivity, Spatial Inequity, and Child Development. At the meso and micro levels, an additional Comfort lens is included to capture the child's real-time sensory experience.

10.4.1. Macro-scale indicators

This level focuses on the urban context—neighborhood infrastructure, environmental quality, and mobility conditions that affect children on their everyday commute to and from school. Indicators are used to identify schools located in high-risk areas and assess the quality of the pedestrian and ecological networks connecting to the school.

The analysis of the urban environment around schools is structured in two complementary parts. Part A focuses on the overall quality of the street network and pathways connecting children's homes to school, with particular attention to pedestrian infrastructure, safety, and access to movement-promoting urban features.
Part B zooms in on critical crossings and transport nodes, evaluating their design quality through six thematic lenses.

In Part A, the indicators examine elements such as sidewalk continuity, crossing density, bike lane presence, block connectivity, and traffic exposure. These indicators directly influence children's ability to safely and independently commute to school—contributing to both their daily physical activity levels and to spatial equity, defined as fair and inclusive access to safe, healthy, and appealing public spaces.

For this reason, the lenses of physical activity and spatial inequity are merged at this scale, as they rely on many of the same spatial and infrastructural determinants. Walkability, street safety, and proximity to active and green spaces are not only critical for mobility but also reflect broader patterns of urban justice and the distribution of opportunity.

Table 10.4.1. Macro scale indicators - Part A

Lens	Indicator name	Metric	Methodology	Purpose
Urban Heat Island (UHI)	Tree canopy cover	% canopy cover along access routes	GIS NDVI or aerial image analysis	Evaluate natural shade and heat mitigation capacity
	Shade availability	% of pedestrian route shaded during peak sun (12–15h)	Shadow mapping using GIS or site photos	Assess sun exposure during active travel hours
	Heat-absorbing surfaces	% of impervious/dark surfaces along route	Street material mapping + albedo data	Identify surfaces contributing to urban heat buildup
	Ventilation potential	Presence of open corridors/low obstruction zones	Urban morphology analysis or visual inspection	Check for natural airflow and cooling potential
Stormwater Ruonff	Surface permeability	% permeable vs sealed areas along access routes	GIS surface type classification	Assess potential for water absorption and runoff control
	Presence of stormwater infrastructure	# of visible drains, bioswales, or rain gardens per 100m	Field audit or drainage map analysis	Evaluate surface water management along walking paths
	Ponding and waterlogging zones	# of observed water accumulation sites	Post-rain field audit	Identify zones where children may face barriers or hazards due to runoff
Biotope Loss	Green availability	% green space within a 100m buffer of the route	GIS green space analysis	Evaluate exposure to nature along everyday school paths
	Green connectivity	Length and continuity of vegetated corridors	Landscape continuity analysis in GIS	Assess ecological and experiential continuity along routes
	Biodiversity potential	# of species or habitat types observed	Rapid field inventory or urban biodiversity score	Estimate experiential richness and ecological function
Phyisical Activity & Spatial Inequity	Sidewalk continuity and width	% of route with continuous sidewalks ≥ 1.5 m wide	GIS + field audit or Google Street View	Assess if walking is physically possible and safe for children
	Bike path coverage	% of school access routes with dedicated or protected bike lanes	Mapping via OpenStreetMap / city GIS/field survey	Evaluate if biking is a viable and safe commuting mode
	Pedestrian crossing density	Avg. distance between crossings (m) along school access paths	Route mapping + field/ GIS counting	Determine walkability and safety at intersections
	Traffic speed exposure	% of route passing through ≥ 30 km/h speed zone	Street classification review + city open data	Identify stressors and danger zones for child commuters
	Block connectivity	Average block length (m) or number of intersections per km²	GIS network analysis	Assess directness and route flexibility (shorter, safer paths)
	Movement-promoting amenities	# of parks, open spaces, or sports courts within 250 m of main access routes	GIS amenity buffer analysis	Evaluate whether movement is supported near access paths
	Multi-modal space sharing	Presence of designated zones for alternative movement (scooters, skate, jogging)	Field observation or policy mapping	Assess the diversity of supported child-friendly commuting types
Child Development	Sensory and cognitive stimuli	# of diverse urban features (murals, textures, nature, play) per 100m	Walkthrough observational checklist	Support curiosity and sensory engagement
	Opportunity for autonomy	% of route where children can walk independently (age-adjusted)	Parental survey or observational scoring	Assess perceived and real independence potential
	Presence of learning affordances	# of educational or playful elements (signage, art, science features)	Field survey or child-participant mapping	Capture informal learning potential during commute

Table 10.4.1. Macro scale indicators for evaluation of street crossings, public transport stops, and stations - Part B

Lens	Indicator name	Metric	Methodology	Purpose
Street Crossing				
Urban Heat	Shade coverage at/ near crossing	% of pedestrian area shaded by trees/structures	Shade mapping/field audit	Reduce thermal exposure while waiting
Stormwater Runoff	Drainage at pedestrian crossings	Presence of stormwater drain/ permeable paving (Y/N)	Visual audit/drainage mapping	Prevent water pooling and maintain usability
Biotope Loss	Green buffers and vegetation integration	Presence of native vegetation or green medians (Y/N)	Observation or ecological plan review	Enhance ecological connectivity and comfort
Physical Activity	Walkable and bikeable access	Safe, direct connection to walking/biking paths (Y/N)	GIS route mapping + field audit	Support active commuting and school journeys
Spatial Inequity	Step-free accessible crossings	Presence of curb ramps and tactile paving (Y/N)	Field observation / universal design checklist	Ensure inclusive, safe, and visible crossing conditions
Accessibility	Refuge islands and signalization for wide crossings	Presence of islands, tactile or auditory signals (Y/N)	Crossing layout + sensory feature audit	Support safe crossing for all users, including the visually impaired
Child Development	Child-visible signage and sensory features	# of visible signs, murals, or textures for engagement	Field inventory	Stimulate spatial awareness, autonomy, and learning
Public transport stops & stations				
Urban Heat	Shade coverage at the stop	% of waiting area covered by trees, canopies, or overhangs	Shade mapping/field audit	Reduce heat exposure during wait
Stormwater Runoff	Weather protection from rain	Shelter and wind-blocking roof (Y/N)	Visual design audit	Maintain usability during rainfall
Biotope Loss	Integrated planting (e.g., green walls)	Presence of greenery in structural stop design (Y/N)	Observation or plan review	Enhance biodiversity and aesthetics
Physical Activity	Walkable and bikeable access	Presence of connected paths (Y/N)	GIS route mapping + field check	Promote active travel to the stop
Spatial Inequity	Step-free access and curb ramps at transit stops	Presence (Y/N)	Field observation / universal design checklist	Ensure basic accessibility and inclusive entry
Accessibility	Wheelchair access to the platform	Presence (Y/N) of mechanical/low-floor access	Audit + transit design standards	Guarantee access for users with reduced mobility
Urban Furniture Accessibility	Accessible urban furniture placement	Obstruction-free distance ≥ 1.20 m (Y/N)	Furniture layout observation	Prevent movement barriers for wheelchair users
Child Development	Educational/ interpretive elements	# of learning stimuli (maps, info signs, nature features)	Field inventory	Encourage informal learning during transit wait

10.4.2. Meso-scale indicators

The meso scale focuses on the school as an integrated system—examining how the building, entrance areas, and schoolyard interact to shape both climate-related risks and developmental opportunities. This scale addresses the thresholds between indoor and outdoor spaces, exploring how the quality of the building envelope, the design of entrances, and the spatial relationship with the schoolyard influence comfort, accessibility, and everyday routines.

At this level, indicators examine how design choices at the building–yard interface affect exposure to urban heat, stormwater accumulation, biodiversity loss, and noise or air quality, as well as how these spaces support physical activity, inclusive access, and child development. Particular attention is given to features such as façade orientation and material reflectivity, paving and planting at entrances, window design, shading systems, green walls, and biodiversity-supportive elements like birdhouses and insect hotels.

This scale also considers how the building layout—through its visual connections, direct outdoor access points, and multi-functional thresholds—can stimulate movement and outdoor engagement. Ultimately, the goal is to understand how the ecological and spatial performance of the school's built form can buffer environmental stressors, enhance thermal and acoustic comfort, promote active, healthy routines, and enable daily learning and development.

Table 10.4.2. Meso scale indicators.

Lens	Indicator name	Metric	Methodology	Purpose
School Entrance				
Urban Heat	Shade at exits/ transition zones	% of shaded area over waiting zone	Shade mapping	Enhance thermal comfort
	High-albedo surfaces	Surface reflectance (%)	Material specification review	Minimize surface heat absorption
Stormwater Runoff	Drainage at thresholds	Presence of grates or permeable paving (Y/N)	Visual/plan audit	Avoid water buildup at access points
	Infiltration zones/ tree pits	Presence + m²	Landscape audit	Enable absorption and biodiversity
	Covered walkways	Length or % of entrance area covered	Infrastructure survey	Keep walking paths dry
Biotope Loss	Vegetation at the entrance	Presence + species count	Plant inventory	Support biodiversity and aesthetics
	Biodiverse landscaping	Presence of pollinator/ supportive species (Y/N)	Landscape inventory	Promote ecological function and beauty
	Permeable green surfaces	% of softscape/ permeable green	Surface mapping	Enhance runoff control and microhabitat
Physical Activity	Active travel amenities	Presence of bike racks, scooter parking (Y/N)	On-site inventory	Support active mobility options
Spatial Inequity	Barrier-free entryways	Presence (Y/N)	Entrance design audit	Eliminate physical obstructions and improve flow
	Tactile paving and signage	Presence (Y/N)	Visual audit	Aid navigation for visually impaired users
	Seating near the entrance	# of benches with backrest/armrest	On-site inventory	Support rest and comfort for vulnerable users
Child Development	Child-friendly spatial markers	# of visual or playful design elements	Inventory audit	Support recognition, safety, and positive experience

Lens	Indicator name	Metric	Methodology	Purpose
Building-Yard Interface				
Urban Heat	Shade presence	% of shaded interface area	Shade mapping	Reduce thermal discomfort around the building
Stormwater Runoff	Rain protection at thresholds	Length/depth of protected entry (m)	Plan and field measurement	Prevent water intrusion and discomfort
	Drainage strip at door thresholds	Presence (Y/N)	Detail inspection	Prevent water entry indoors
Biotope Loss	Planters or green borders near exits	# or length of planting zones	Field measurement	Create continuity in ecological function
Child Development	Visibility and accessibility of outdoor play	Visual connection score or # of direct exits	Plan and observation analysis	Stimulate spontaneous transition to play
Physical Activity	Material and sensory continuity	Visual/tactile match score	Qualitative audit	Support sensory-rich and coherent transition
	Open access to movement space	Direct connection to large activity zones (Y/N)	Layout assessment	Facilitate active transitions and recess use
Comfort	Acoustic insulation of building skin	Facade/window sound insulation (dB)	Technical performance spec	Ensure interior calm near noisy outdoor areas

Lens	Indicator name	Metric	Methodology	Purpose
Building				
Urban Heat	Building orientation and solar exposure	% of facade with peak solar exposure	Sun path analysis / 3D simulation	Control overheating of interior zones
	Facade material reflectivity	Surface reflectance index (%) or SRI	Material specification or IR scan	Minimize solar heat absorption on the facade
	Paved surface albedo near the building	Average albedo of pavement (value)	Material audit/ reflectivity index	Limit heat gain near the building perimeter
	Facade shading devices	Presence and type per orientation	Plan/facade section review	Reduce indoor heat loads
	Vegetated shading (green screens, vines)	% of green-covered vertical surface	Visual survey/ planting plan	Provide cooling and habitat function
	Window-to-wall ratio	% glazed surface per facade	Elevation drawing or BIM analysis	Balance daylight with thermal performance
Stormwater	Rainwater harvesting system	Presence (Y/N), storage capacity (litres)	Technical documentation review	Enable reuse and stormwater mitigation
	Greywater recycling	Presence (Y/N), daily reuse capacity	Infrastructure audit	Support water efficiency
	Green roof capacity	m² and depth/type of green roof	Plan + spec audit	Retain rainwater and insulate the roof
	Permeable zone near facade	% of adjacent surface that is permeable	Landscape plan/field audit	Enable infiltration and reduce runoff
Biotope Loss	Insect hotels or birdhouses	# and type integrated in structure	On-site biodiversity inventory	Enhance habitat diversity on building skin
	Biodiverse green facade	Species count + coverage area	Ecological planting plan analysis	Support pollinators and urban wildlife
	Green roofs/ vertical gardens	Green coverage area (m²)	Plan and elevation analysis	Increase habitat and thermal performance
	Rooftop biodiversity features	Presence (Y/N), # of microhabitats	Green roof design audit	Create ecosystems on the roof surface
Child Development	Outdoor view from classrooms	% of classrooms with a view of green/play zones	Plan review + observational test	Stimulate cognitive and emotional well-being
	Window sill height and transparency	Height from floor (cm) and % clear glass	Architectural section analysis	Ensure child-scale visual connection
	Facade-integrated learning elements	Presence (Y/N), # of features (e.g., murals, signs)	Visual inventory	Create an educationally rich environment
	Direct exits from class clusters to the outdoors	# of doors per learning unit	Plan layout review	Promote active and flexible learning modes

10.4.3.Micro-scalee indicators

The micro scale zooms in on the child's direct experience within the schoolyard—how it feels, what it offers, and how it supports daily activities like play, rest, and exploration. This level assesses comfort, stimulation, and inclusion at the human scale, considering real-time conditions such as shade, surface temperature, noise, and air quality at child height. It also looks at how layout and features invite movement, imagination, and social interaction. Micro-scale indicators help capture whether the space truly works for children—not just in design intentions, but in daily use—and whether it supports their physical, cognitive, social, and emotional development.

Table 10.4.3 Micro-scale indicators.

Lens	Indicator name	Metric	Methodology	Purpose
Urban Heat	Presence of shaded zones	% of yard area with tree or artificial shade	Shade mapping	Mitigate thermal stress and support usability
	Green-to-grey surface ratio	% of permeable/ vegetated surface	Site measurement/ plan audit	Reduce heat and increase evapotranspiration
	% sshase area	%	Calcolo da mappa solare	Indicates the quality of outdoor comfort.
	Albedo of pavement materials	Surface reflectivity value	Material specification review / IR scan	Prevent heat accumulation on site
	Average Pavement SRI	Indice	Scheda tecnica materiali	Solar reflectance capacity
	Surface area of water features/water points	m² / units	Site plan / direct field survey	Natural cooling and ecological value
Stormwater Runoff	Superficie coperta / superficie scoperta	m² e %	Planimetria / rilievo diretto	Rapporto suolo/edificio, drenaggio, UHI
	Permeable paving and infiltration zones (permeable, semi-permeable, impermeable)	Surface area with permeable treatment (m² or %)	Site plan and material audit	Enhance drainage and reduce runoff risk
	Rainwater harvesting or retention system	Presence (Y/N) + volume capacity	Infrastructure inventory	Enable reuse and reduce stormwater impact
	Vegetated retention zones (bioswales, tree pits)	Presence and m²	On-site mapping	Support water management and ecological services
Comfort	Shade over furniture	Yes/No	–	Absence of furniture = no functional shade
	Condition of outdoor furniture	Scale 0–3	– (Document with photos)	Assess usability and maintenance status
	Presence of shelters/ canopies / shading devices	Yes/No	Direct observation	No protection from the sun/ rain
Biotope Loss	Biodiversity index	# of native species or vegetation layers	Ecological inventory	Support ecosystem regeneration
	Edible or sensory planting zones	Presence (Y/N)	Field inventory	Foster nature connection and learning
	Habitat features (logs, insect hotels, etc.)	Presence (Y/N)	Observation audit	Support microhabitats for biodiversity
	Green area	m²	Planimetria / rilievo diretto	Influenza microclima e benessere psicologico

Lens	Indicator name	Metric	Methodology	Purpose
Physical Activity	Flexible open areas	Total m² of unstructured play space	Area calculation	Enable free play and spontaneous activity
	Diverse movement zones	# of distinct zones for movement types	Site plan analysis	Stimulate different forms of physical activity
	Open play zones	Area in m²	Field mapping/site plan	Support unstructured physical activity
	Movement circuits or marked paths	Presence (Y/N), length (m)	On-site observation	Promote structured physical activity
	Climbing/play structures	Count and diversity of equipment	Equipment inventory	Support gross motor development
Spatial Inequity	Universal design in paths and play equipment	Presence of accessible paths and features (Y/N)	Accessibility audit	Ensure inclusive access and use
	Comfort infrastructure (shade, benches, water)	# of comfort features	On-site count	Equalize the quality of experience
	Condition and distribution of elements	Evenness across yard zones (qualitative)	Visual mapping	Avoid clustering of quality in one area
	Superficie complessiva del lotto	m²	Planimetria catastale	Calcolo % spazi esterni, densità d'uso
	Superficie totale cortile	m²	Planimetria / rilievo diretto	Quantifica disponibilità spaziale complessiva
	Presenza sedute	no	Osservazione diretta	Registrare assenza
Child Development	Outdoor learning spaces	# of designated learning nodes	Plan and use mapping	Foster pedagogical use of outdoor space
	Nature play elements	Presence (Y/N)	Inventory of logs, soil, sand, and water	Promote unstructured, sensory-rich play
	Diverse affordances for play and learning	# of different types (loose parts, climbables, sensory)	Affordance mapping	Support cognitive and physical development
	Quiet retreat zones	Presence and size of calm space (Y/N, m²)	Observation or layout check	Support emotional regulation and privacy
	Morfologia e organizzazione degli spazi :	Adiacenti	Osservazione diretta / interviste	Supporta analisi funzionale e partecipata
	Nature play areas	Presence and diversity of natural materials	Field observation	Stimulate sensory and cognitive development
	Learning gardens or outdoor classrooms	Presence (Y/N), m²	On-site observation or plan review	Enhance outdoor learning opportunities
	Zones for quiet or self-regulation	Number and quality of cozy/quiet corners	Field mapping + child interview	Support emotional regulation and autonomy
	Presence of tables	Yes/No	Direct observation	No support for outdoor activities

Conclusions

Part IV serves as the bridge between the conceptual foundation established in the earlier parts of this research and its practical application. By grounding the REACTIVEFramework in interdisciplinary theory, comparative best practices, and co-design methodologies, this section demonstrates how a robust analytical model can be systematically translated into a transparent, actionable methodology.

The **REACTIVE Framework and Toolkit**, developed through this research, represents the primary output of the doctoral work. It synthesizes the findings into a structured system of principles, processes, and tools for transforming schoolyards into climate-resilient, health-promoting, and developmentally supportive environments.

Its operational form, including the complete toolkit, audit system, design guidelines, and co-design materials, is presented in the Annex as a **ready-to-use guide** for practitioners, municipalities, and school communities. This ensures that the research outcome is both scientifically grounded and directly applicable in real-world contexts.

PART V -

Final considerations

11. Summary of findings

This doctoral research has addressed the growing need for climate adaptation and health promotion within urban public spaces by focusing on the transformation of school-related environments. Positioned at the intersection of urban design, public health, and climate science, schoolyards represent a unique opportunity to operationalize climate resilience and child well-being at the neighborhood scale.

In detail, the research explores the intersection of climate change, public health, and child development through the lens of school-related environments.
The main output is the REACTIVE Framework and Toolkit, designed to guide the transformation of schoolyards into climate-resilient, health-promoting, and developmentally supportive spaces.

The findings can be summarized as follows:

- **Identification of Schoolyards as Strategic Urban Assets**: Schoolyards are reframed as hybrid socio-ecological infrastructures capable of delivering multiple co-benefits (climate resilience, child health, social inclusion) at the neighborhood scale.
- **Development of an Integrated Analytical Methodology:** The research consolidates literature, best practices, and systemic analysis into a structured, multi-scalar audit system that evaluates climate risks, environmental performance, and child health determinants.
- **Toolkit Structure and Outputs:**
- **Five Lenses** (Child Development, Climate Resilience, Biotope Loss, Physical Activity, Spatial Inequity)
  - Three Scales (Macro, Meso, Micro)
  - Indicators & Audit Tools for technical and participatory use
  - Design Guidelines contextualized for diverse urban conditions
- **Knowledge Transfer:** The research provides a format adaptable for municipalities, designers, and schools, aligning academic knowledge with real-world operational needs.

11.1. Contributions to academic knowledge & practice

The REACTIVE Framework and Toolkit represents the principal contribution of this doctoral research, integrating climate adaptation, health promotion, and child development into a unified approach for the transformation of school-related environments.

Its added value lies in its dual impact: advancing academic knowledge by proposing an interdisciplinary, evidence-based conceptual model, and serving professional practice by providing a structured, operational toolkit for design and planning. This dual orientation ensures that the research is both scientifically robust and applicable in real-world contexts, bridging the gap between theory and implementation.

By investigating the links between climate-related risks, environmental quality, and child development, the research has made the following contributions to academic knowledge:

- **Theoretical Advancement:** Positions schoolyards within an integrated risk–resilience–health framework, grounded in climate science (IPCC AR6) and child development theories (WHO, UNICEF, Halfon et al.).
- **Systems Integration**: Introduces a design methodology linking environmental determinants, spatial qualities, and health outcomes in a structured audit–design–evaluation loop.
- **Literature Synthesis:** Combines 40 years of best practices with interdisciplinary research, creating an evidence-based foundation for resilient schoolyard design.

In professional practice, the REACTIVE Framework offers a structured resource that translates research findings into actionable tool. It supports practitioners in integrating climate resilience, health promotion, and inclusivity into schoolyard transformation, with the following key contributions:

- **Practical Toolkit:** Produces an operational REACTIVE Framework & Toolkit, ready for application in design and planning processes.
- **Scalability**: Methodology is adaptable to varying contexts, from strategic policy planning (macro) to site-specific design (micro).
- **Participatory Approaches:** Incorporates co-design tools and simplified audits to bridge technical knowledge and community engagement.
- **Cross-sector Relevance:** Provides actionable guidance for architects, planners, public health experts, and educational authorities.

11.2. Reflections and Limitations

The research followed a transdisciplinary and systemic methodology that merged literature analysis, case study synthesis, and systems mapping to translate complex evidence into a structured, practical framework for climate-resilient schoolyard design. While this approach enabled a comprehensive view of the problem, it also introduced several limitations, such as:

- **Lack of Empirical Validation:** The toolkit has not yet been tested through real-world pilot projects within the thesis timeframe. Its operational feasibility, user-friendliness, and measurable outcomes remain to be validated.
- **Health Evidence Link**: While the framework links design strategies to potential health benefits, it does not quantify direct health impacts due to the complexity and multi-factorial nature of health outcomes.
- **Geographic Scop**e: Although informed by international best practices, the framework is primarily shaped by the Mediterranean/European context, and adaptation may be needed for different climatic, cultural, and institutional environments.

Despite these limitations, the research delivers a valuable methodological and conceptual contribution to the field of climate-responsive design, with a specific and underexplored focus on schooly-related environments as strategic urban spaces.

11.3 Future Developments

REACTIVE framework and toolkit developed through this research will serve as the basis for upcoming practical applications and further refinements. In particular, its implementation and validation are planned through the newly launched Interreg Euro-MED project, which will support pilot actions in diverse Mediterranean cities.

The gaps identified in Chapter 5 point to opportunities for deepening knowledge, testing the framework, and extending its applicability such as:

- **Pilot Testing and Validation:** Implementation in pilot schoolyards (e.g., through RE-ACT Schools) will allow practical testing of the audit, design bundles, and co-design tools, generating data on environmental performance, inclusivity, and usability.
- **Health and Developmental Outcomes**: Collaborations with public health experts could strenghten pre/post-intervention evaluations, linking environmental changes to thermal comfort, activity levels, and cognitive benefits.
- **Digital Toolkit Development:** Translating the toolkit into an interactive digital platform can enhance scalability, adaptability, and integration with GIS and climate-health data.
- **Extension to Other Urban Spaces:** The REACTIVE methodology can be applied to other child-related micro-urban environments (e.g., playgrounds, school streets, parks) to test its transferability.
- **Expansion to Other age and/or vulnerable groups**: The REACTIVE Framework can be further expanded to include other users.
- **Strengthening NbS Evidence:** Further research on the ecological and multifunctional performance of Nature-Based Solutions (NbS) in school contexts can refine design recommendations and improve selection criteria.

In summary, future research should focus on validation, health impact assessment, policy integration, digital adaptation, cross-context application, and NbS evidence. These steps will consolidate the REACTIVE Framework as both a research-based model and a scalable practical tool for diverse contexts.

This thesis concludes with the delivery of REACTIVE Framework and Toolkit ready for application. Its validation and iterative improvement will be carried out through the upcoming international research project, allowing for further scientific and practical consolidation.

Figure 11.3 Testing the co-design materials within RE-ACT Schools project.

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