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Francesco Alberti · Simon Elias Bibri · Cristina Piselli ·
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Urban and Transit Planning (Vol 1): Strategies, Innovations and Climate Management

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Editors

Urban and Transit Planning (Vol 1): Strategies, Innovations and Climate Management

A culmination of selected research papers from the International Conference on Urban Planning and Architectural Design for Sustainable Development (UPADSD)—8th Edition—University of Florence, Italy

Springer

Editors
Francesco Alberti
Department of Architecture (DIDA)
University of Florence
Florence, Italy

Cristina Piselli
Department of Architecture (DIDA)
University of Florence
Florence, Italy

Abraham R. Matamanda
Department of Urban and Regional Planning
University of the Free State
Bloemfontein, South Africa

Rosa Romano
Department of Architecture (DIDA)
University of Florence
Florence, Italy

Simon Elias Bibri
School of Architecture
Civil and Environmental Engineering (ENAC)
Swiss Federal Institute of Technology Lausanne
Lausanne, Switzerland

Paola Gallo
Department of Architecture (DIDA)
University of Florence
Florence, Italy

Hamid Rabiei
School of Architecture
University College Dublin
Dublin, Ireland

Ayse Ozcan Buckley
Department of Political Science and Public Administration
Giresun University
Giresun, Türkiye

ISSN 2522-8714 ISSN 2522-8722 (electronic)
Advances in Science, Technology & Innovation
IEREK Interdisciplinary Series for Sustainable Development
ISBN 978-3-031-76095-2 ISBN 978-3-031-76096-9 (eBook)
https://doi.org/10.1007/978-3-031-76096-9

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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The Editors warmly thank all the Reviewers who have contributed their authority to the double-blind review process, to ensure the quality of this publication.

Preface

The challenges of sustainability in the context of urban planning and the achievement of the SDGs are interrelated. Urban sustainability and the Sustainable Development Goals need to go hand in hand. Cities are critical in responding to the urgent need for environmental, economic, and social sustainability. In recognition of the urgency of sustainability in cities, the 8th edition of the Urban Planning & Architectural Design for Sustainable Development (UPADSD) Conference (October 24–26, Florence, Italy) focused on sustainable strategies in terms of urban and transit planning and the potential of green infrastructure and culture within the same context to support the global agenda for sustainable development. It thus provided a roadmap for integrating sustainability into relevant plans, programs, and decision-making processes in urban planning and urbanism.

This book is part of the peer-reviewed Advances in Science, Technology & Innovation (ASTI) book series presenting the IEREK Interdisciplinary Series for Sustainable Development. The book is therefore an edited collection of papers from the 8th International Conference on Urban Planning & Architectural Design for Sustainable Development (UPADSD), which presents groundbreaking research through the intersection of urban sustainability and sustainable development goals under two separate volumes. Volume 1 includes articles on strategies, innovations, and climate change in the context of urban and transport planning. Volume 2 contains articles on culture and sustainability for the built environment, focusing on the same context of urban and transit planning. In this regard, the first volume presents the indexing of articles under the following three headings: (1) Urban Design Strategies for Climatic Mitigation, (2) Urban Design (regarding development and management), and (3) The Future of Urbanism and Sustainable Design. The second volume similarly consists of articles categorized under the following different headings: (1) Integrating Art and Culture in Urban and Architectural Landscapes, (2) Reinventing the Built Environment: Emerging Trends and Innovations) and (3) Innovations in Architectural Methods and Technologies.

The book covers a wide range of academic disciplines in sustainability, including green urbanism and nature-based solutions, energy efficiency and renewable energy in architecture, renewable energy systems, climate-resilient infrastructure, sustainable transport, and reliable transit systems, urban forms within the urban design, development, and management context, innovations in architectural design methods and technologies, policy, and governance. It also incorporates the latest developments and research in urban sustainability studies that contribute to more sustainable cities, such as infrastructure, civil engineering, geology, mining, water and natural resource conservation and management. The emphasis is on ideas that can influence public policy to promote sustainable urban planning and management, air and water pollution control, and green infrastructure.

The editors would like to thank the chairs of the IEREK group for their support and assistance in the editorial process. We would also like to thank colleagues from related academic disciplines who agreed to review and comment on the articles. We hope that this series will foster collaboration among the members of the IEREK group and attract other interested researchers by showcasing the significant developments taking place within the context of IEREK Urban Sustainability Studies.

Florence, Italy — Francesco Alberti
Lausanne, Switzerland — Simon Elias Bibri
Florence, Italy — Cristina Piselli
Florence, Italy — Paola Gallo
Bloemfontein, South Africa — Abraham R. Matamanda
Dublin, Ireland — Hamid Rabiei
Florence, Italy — Rosa Romano
Giresun, Türkiye — Ayse Ozcan Buckley

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Introduction

In December 2005, the great British urbanist Peter Hall, to whom we pay tribute here ten years after his death, delivered the first “Enfant Lecture on City Planning and Design” at the Building Museum in Washington, DC, an American Planning Association event that has since become an annual event. The title of the lecture, published a few years later in an edited book on “Green Communities” (Routledge 2009), was at once ironic and provocative: “The Sustainable City: A Mythical Beast?”

The question can be rephrased as follows: is urban sustainability, beyond the statements of principle and much rhetoric on the subject, destined to remain a myth, or can it be practically realized?

Almost two decades later, the doubt is more legitimate than ever.

At the halfway point, the 17 Sustainable Development Goals of the UN 2030 Agenda appear far from on track to meet the deadline: 30 percent of the goals, including key targets on poverty, hunger and climate, are now stalled or even lagging behind the progress already made since the Agenda was launched in 2015.

The Sustainable Development Goals Report 2023 highlights how the deepening climate crisis, ongoing conflicts, and the legacy of the global pandemic of COVID19 are putting the entire process at risk and dramatically widening the gap between the global North and South. “Unless we act now,” warns United Nations Secretary-General António Guterres in his foreword of to the Report, “the 2030 Agenda could become an epitaph for a world that might have been.”

Goal 11—Sustainable Cities and Communities—also sets the pace. Although in this case at a gradually decreasing rate, urban sprawl is outpacing population growth in most cities, with negative implications for sustainability; a growing urban population is unable to find affordable housing and lives in slums or slum-like settlements, not only in megacities but also in medium-sized cities; convenient access to public space and transport remains a mirage in most developing countries. In the absence of integration between environmental, social and economic policies, the confusion between real and cosmetic sustainability (greenwashing) undermines the message of a genuine paradigm shift.

Yet, today even more than 19 years ago, the signs of change in the way urban issues can be addressed to drastically reduce their overall impact on the planet and its inhabitants, human and non-human, entitle us to cultivate the same wise optimism that led Peter Hall to affirm in his lecture that urban sustainability is a possible utopia. Or at least it could be, if we systematize the innovations being tested in different corners of the world –“What we need to do above all is to learn from best practices, to learn from each other. And so (...) we need more research”.

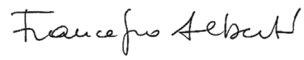
It is in this furrow of hope and commitment for a world that can still grasp the great potential of collective consciousness raising, where the sharing of knowledge and the awareness that we are all in the same boat prevails over the divisions that threaten the globe as much as natural disasters (while, on the contrary, exploiting differences), that the studies collected in this book are located.

The book—an edited selection of papers presented at the 8th International Conference on Urban Planning & Architectural Design for Sustainable Development (UPADSD), held in Florence (Italy) from October 24 to 26, 2023—presents cutting-edge research through the intersection of two main areas under two separate volumes, dedicated to studies, approaches and experiments concerning the urban, metropolitan and regional scales, and, respectively, the built environment—buildings and components.

In this first volume, the focus is on ideas that can influence public policy to promote sustainable urban and transportation planning and management, while addressing energy transition, climate mitigation and adaptation, disaster risk reduction, revitalization of deprived neighborhoods and historic settlements, and other important issues affecting the future of cities and territories.

The wide repertoire of case studies described reflects the need to evaluate similar issues in the specificity of local contexts, even when inspired by available best practices.

Francesco Alberti



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School Facilities as a Driver and Tool of Urban Climate Strategies. *The Green Schools of Lucca* Initiative as a Case Study

Francesco Alberti and Maria Rita Gisotti

Abstract

The paper presents the results of a research study commissioned by the Municipality of Lucca (Italy) and carried out by a research group from the Department of Architecture of the University of Florence, with the aim of verifying the benefits of greening projects for 18 preschools and primary schools and the rehabilitation of a public park in terms of mitigating the effects of the increasingly frequent heat waves affecting the city. The analysis, carried out with the help of a climate simulation software, highlighted the positive and negative aspects of the project, and laid the foundations for the definition of a methodology to be applied to future interventions, integrating the objective of increasing urban resilience to climate change with that of making school spaces more liveable for pupils, following a line of action research that already counts numerous experiences in Europe.

Keywords

Adatptation to climate change • Schools • Urban greening • Resilient city • Healthy city

1 Introduction

International policies launched in recent years to fight the effects of climate change and promote ecological transition (Agenda 2030, European Green Deal, New European Bauhaus, Sustainable Energy Action Plan, European Climate Law, Nature Restoration Law) affirm the need to reduce soil sealing, gain more space for urban greening and call for solutions that integrate nature into the urban fabric (European Commission 2015; European Commission 2020). A vast field of experimentation has been developed based on the use of Nature-Based Solutions in urban regeneration projects, to achieve the integration of different benefits (Kabisch et al. 2017; Choi et al. 2021; Alves et al. 2024), i.e., the reduction of urban heat islands, the increase in biodiversity, the restoration of soil permeability and of water infiltration, the redevelopment of the urban landscape, more public space for people.

Overall, this type of projects outlines the horizon of a more liveable and healthier city, while not being free from generating negative effects such as the risk of triggering processes of environmental gentrification (Checker 2011) and ecological gentrification (Pearsall and Anguelovski 2016). To this end, the importance of acting according to a logic of infiltration of green and blue infrastructures in the urban fabric has been demonstrated (Marot and Catsaros 2020; De Sousa Silva et al. 2018). The idea is to create a widespread green network that penetrates the city, rather than acting for large, isolated projects, linked the inequalities. From this perspective, school open spaces represent a strategic opportunity: they are public facilities located in cities according to the criteria of proximity and uniform distribution in neighborhoods formulated by modern urbanism (Bricocoli et al. 2022; Marchigiani and Bonfantini 2022). This is also why working on these spaces can contribute to supporting the implementation of the European Green Deal at the local level, pursuing a place-based ecological transition, that is more effective and just (Gisotti and Masiani 2024). In recent years (and with greater impetus since the Covid-19 pandemic), many projects have acted in this direction, especially in the European context.

This paper contributes to the debate on schools and urban regeneration aimed at mitigating and adapting to climate change, arguing that such interventions should be guided by

F. Alberti (✉) · M. R. Gisotti
Department of Architecture DIDA, University of Florence, Florence, Italy
e-mail: francesco.alberti@unifi.it

M. R. Gisotti
e-mail: mariarita.gisotti@unifi.it

F. Alberti et al. (eds.), *Urban and Transit Planning (Vol 1): Strategies, Innovations and Climate Management*, Advances in Science, Technology & Innovation, https://doi.org/10.1007/978-3-031-76096-9_7

a methodology that allows ex-ante verification of the benefits of greening actions in terms of reduction of surface temperatures and improvement of environmental well-being. This methodology has been identified from the analysis conducted by the authors on an Italian case study, *The Green Schools of Lucca*, a project of the Municipality of Lucca funded by the Ministry for Ecological Transition (MiTE) (ISPRA 2023).

The paper is structured as follows. In the first section we propose a literature review on the role of school open spaces in resilience-oriented urban regeneration. In the second section we present the project *The Green Schools of Lucca*, and in the third the objectives of the research commissioned to the authors of this paper for the evaluation of interventions. The fourth section describes the methodology and analyses carried out, while the fifth section presents the results of the research and discusses them, drawing general conclusions.

2 The Role of Schools in Resilient Urban Renewal

In recent years, numerous regeneration initiatives have been taken in school open spaces (courtyards, gardens, areas around schools) through the adoption of Nature-Based Solutions primarily aimed at mitigating the effects of heat islands: the de-paving of some areas, their replacement with permeable surfaces, the incorporation of shrubs and trees contribute to a reduction in temperature, achieving an improvement in thermal performance that reverberates even in the vicinity of schools (Rivera Gomez et al. 2019; Barò et al. 2022; Bohnert et al. 2022).

Numerous studies have also highlighted the benefits of these rehabilitation interventions and well-designed schoolyards with abundant vegetation on children's health and well-being (Van Dijk-Wesselius et al. 2018; Van den Bogerd et al. 2023). This includes promoting physical activity and fostering social interactions (Bikomeye et al. 2021). Incorporating play structures, recreational spaces, and shaded areas not only encourages outdoor play but also boosts physical activity levels during recess.

The redesigned schoolyards, if open to the public at times and periods when they are normally closed (e.g., at weekends or during the summer months), can be considered true climate shelters (Vetter 2020). Hence, these transformed spaces can evolve into community focal points, fostering climate awareness among families and residents in the surrounding neighborhoods.

Education on ecological transition and resilience is another key issue in this type of project. Often the interventions have been accompanied by participatory processes aimed not only at co-design school open spaces with children and young people but also at creating a new awareness of the issues of climate change, circularity in the use of resources and the benefits of greening, by encouraging more sustainable behaviour (Toomey et al. 2023). Schools can therefore play a central role as hubs for both educational and social experimentation within the community. They have the potential to foster innovative approaches to learning, encourage civic engagement, and advocate for practices that drive social innovation. This perspective aligns with the explicit stance taken by the Organization for Economic Cooperation and Development (OECD) that underlines the need to dismantle physical barriers within school structures and to forge stronger connections with local communities, starting right from the school itself (OECD 2020).

Projects that have led the way in the directions outlined above—integrating interventions of courtyards regeneration with educational purposes and with the creation of new public space on the scale of the neighbourhood—are the *Oasis Project*[1] (2019) in Paris and the *Climate Shelter Project*[2] (2019) in Barcelona (both Urban Innovative Actions). These projects aim to transform schoolyards into climate shelters by reducing the heat island effect and providing a range of possible technological solutions, opening school spaces to citizens during non-school hours, and raising awareness of climate change issues. Moreover, in the case of the *Oasis Project*, it is very relevant to have outlined a methodology and guidelines for upgrading schoolyards based on bioclimatic principles. Schoolyards were redesigned to provide a healthier and more comfortable environment for citizens and were used to promote resource circularity. Examples of the latter included closing the water cycle through natural drainage systems, using rainwater instead of potable water to irrigate green areas and encouraging more responsible use of water resources, creating urban gardens that facilitate food chain proximity, and reducing the environmental impact of food transport.

Other important experiences were in Strasbourg (*Canopy Plan*[3]), Madrid (*Cuidados en entornos escolares*[4]), Rotterdam (*Green Blue Schoolyards*[5]), Hamburg (*Clever Cities Project*[6]), Turin (*Cortili in azione*[7]) and Amsterdam

[1] https://www.uia-initiative.eu/en/uia-cities/paris-call3.
[2] https://www.uia-initiative.eu/en/news/climate-shelters-project-climate-innovation-beat-heat.
[3] https://www.climate-chance.org/en/best-pratices/redesigning-playgrounds/.
[4] https://www.madrid.es/UnidadesDescentralizadas/Sostenibilidad/EspeInf/EnergiayCC/04CambioClimatico/4c3Mad+Natural/M+N2019/Ficheros/03_UrbanismoResilienteM+N2019.pdf.
[5] https://brainbuilding.org/implementation/zoom-in/green-blue-schoolyards/.
[6] https://clevercities.eu/.
[7] https://asf-piemonte.org/cortili-in-azione/.

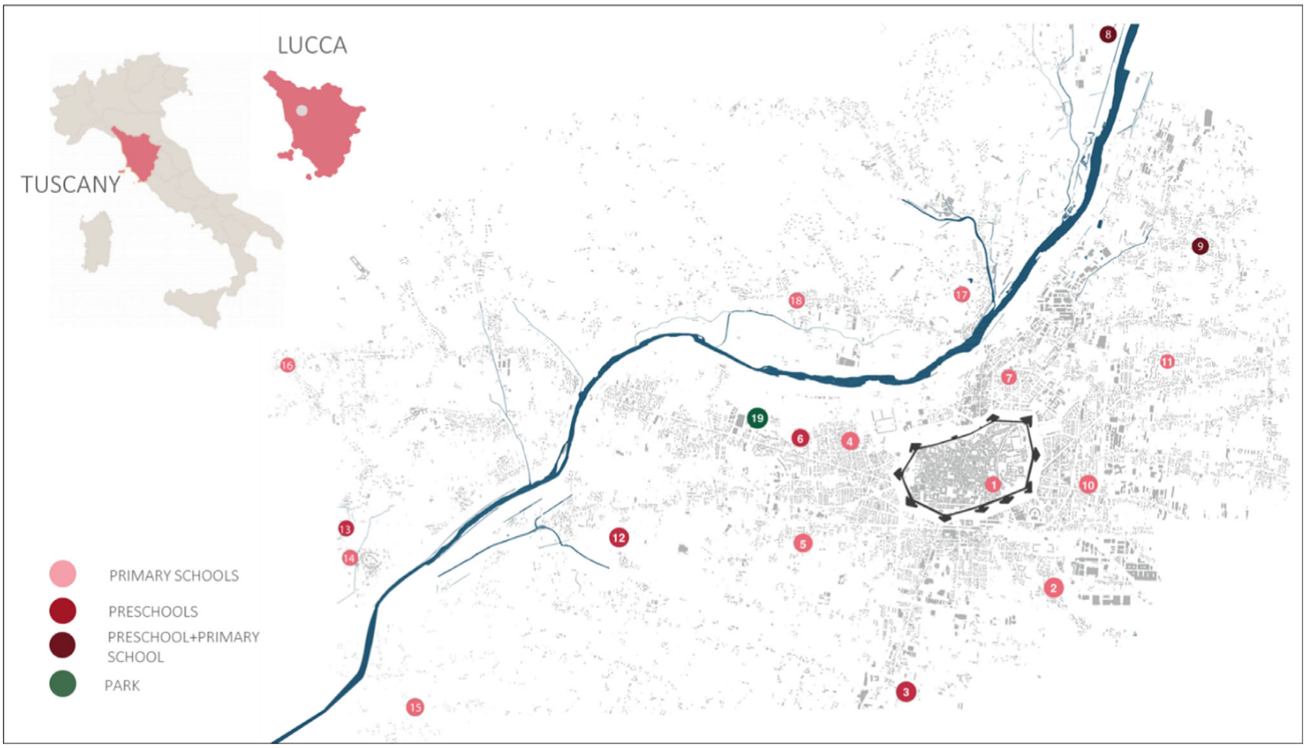

Fig. 1 "*The Green Schools of Lucca*"—location of the project areas in the territory of Lucca (drawing by Martina Bardini)

(*Amsterdam Impuls Schoolpleinen*[8]). The ambitious *Contract d'école*[9] program, based in Brussels, is also relevant for interventions and policies improving school surroundings and the environmental quality of schoolyards, increasing the usability of public spaces and creating welcoming and inclusive spaces for the entire community.

3 "*The Green Schools of Lucca*" Initiative

Against this background, the objective of the study presented here, carried out by the SUP&R (Sustainable Urban Projects & Research) Research Unit of the Department of Architecture of the University of Florence (DiDA),[10] was to evaluate the environmental and climate benefits of the interventions delivered by the project *The Green Schools of Lucca*, a medium-sized city (around 89,000 inhabitants) in Tuscany, 80 km north-west of Florence, the regional capital.

The proposal submitted by the Municipality of Lucca includes the rehabilitation of the grounds of 18 public schools spread throughout the territory and of a park of about 2.3 hectares, the Alcide De Gasperi Park, located in the suburb of Sant'Anna, west of the city center (Fig. 1).

The interventions are aimed at increasing urban resilience to the risks generated by climate change, with a particular focus on mitigating urban heat islands (UHI).

This phenomenon manifests itself as a strong concentration of temperature in the most urbanized areas compared to the surrounding peri-urban or rural areas. In addition, the increased solar radiation due to global warming leads to "spotty" temperature variations within cities due to the density of buildings, the material and chromatic characteristics of sun-exposed surfaces, the presence of vegetation, shading elements, permeable or reflective surfaces, etc. (Santamouris 2013).

According to the Laboratory of Environmental Monitoring and Modelling for Sustainable Development (LaMMA), a public consortium formed by the Tuscany Region and the National Research Centre (CNR), the average annual temperature in Tuscany has already increased by about +0.5 °C between the 1960s and the first decade of the 21st century (LaMMA 2010). In the north-central area of the region,

[8] https://www.amsterdam.nl/sociaaldomein/onderwijs-leerplicht/duurzame-schoolgebouwen/amsterdamse-impuls-schoolpleinen/.
[9] https://perspective.brussels/fr/projets/contrats-ecole.
[10] The research "Studies and assessments to support regeneration projects of public spaces and facilities in the City of Lucca for the purposes of mitigation and adaptation to climate change and in the perspective of a climate neutral city" was carried out by the Research Unit SUP&R (Sustainable Urban Projects and Research) of the Department of Architecture of the University of Florence in the period January-December 2023. The research group was coordinated by Prof. Francesco Alberti with Prof. Maria Rita Gisotti and developed with Martina Bardini, winner of the research grant funded by the Municipality of Lucca.

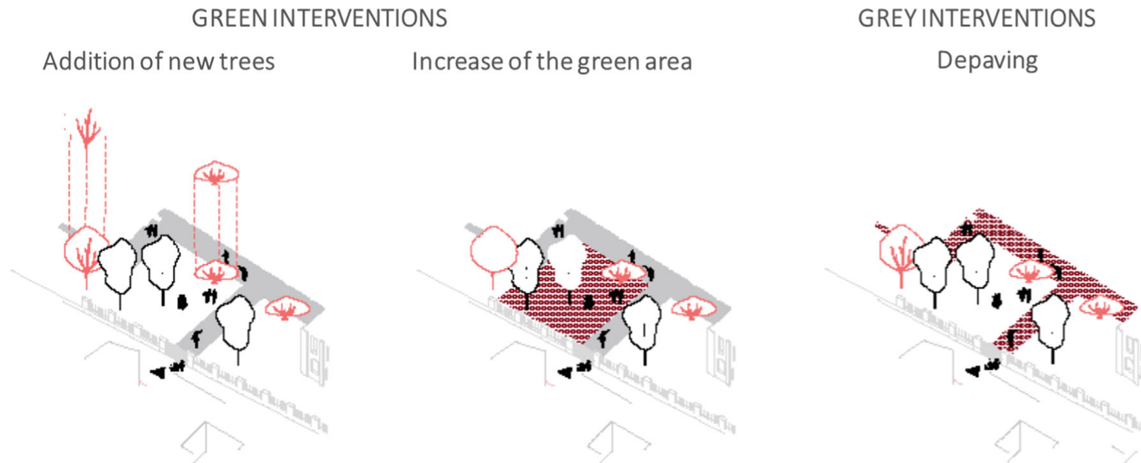

Fig. 2 "Green" and "grey" interventions on the open spaces concerned by the project (drawing by Martina Bardini)

where the province of Lucca is located, this increase in average temperature (corresponding to an increase in maximum and minimum temperatures above the 90th percentile) was as high as +1 °C. In the second decade of the 21st century, the trend became even worse. In the city of Lucca, between 1955 and 2020, 7 of the 10 hottest summers occurred between 2003 and 2020. At the time the *Green Schools* project was presented, the highest temperature recorded in the city was up to +41.5 °C in the summer of 2017. Later, the LaMMa consortium certified that the summer of 2022 was the hottest ever recorded in the entire region.[11]

The recognition of such an alarming trend led to the decision to respond to the first national call for funding for Italian municipalities on climate change mitigation and adaptation with an experimental project aimed at preschool and early school-age children, one of the population groups most vulnerable to heat waves.

In fact, of the 18 schools selected for this pilot project, 5 are preschools, 11 are primary schools and 2 institutions include both levels of education.[12] In terms of location, the choice was mainly made for areas outside the city center: in fact, 10 schools are located in districts built in the nineteenth and twentieth centuries outside the sixteenth and seventeenth century city walls that still delimit the historical center of Lucca, 8 are in peri-urban areas, while only one is inside the walls.

The interventions in the areas selected by the Municipal Administration were designed by a local professional firm, which provided three drawings for each area: (a) current state; (b) final project at 1:1000 and 1:500 scale; (c) executive project at 1:200 scale.

In accordance with the call, the project used two types of interventions (Fig. 2):

- "green" interventions, consisting in the planting of tall deciduous trees (a total of 427 new plants);
- "grey" interventions, consisting of the removal of impermeable pavements and their replacement with permeable and draining surfaces, i.e., grassed areas (a total of 1,834 m^2).

In some areas, the prior removal of existing vegetation was also planned to allow for the planting of new trees with greater leaf density, diameter, and height, thus providing greater shade.

4 Objectives of DiDA's Research to Verify the Climate Benefits of Planned Interventions

Between the design and the implementation, scheduled for 2024 to be managed by the Public Green Office, the Municipality of Lucca commissioned the DiDA research team to quantify the climate benefits resulting from the implementation of the greening measures included in the "Green Schools" project.

Based on this input, the research was developed with a double objective:

[11] https://www.lamma.toscana.it/news/clima-2022-anno-eccezionale-anche-toscana-oggi-alla-1200.

[12] These are respectively 18.75% out of the total of 32 preschools and 41.3% out of the total of 29 elementary school in the City of Lucca.

- on the one hand, in response to the Municipality's request, to provide an assessment of the effectiveness of the designed solutions through the comparative analysis of the ante-operam and post-operam microclimatic conditions in each of the areas involved, carried out through the use of climate simulation software;
- on the other hand, to propose, in the light of the lessons learned from this first experiment, some methodological indications for future interventions in other schools and urban areas, aimed at optimizing the effects of the interventions, not only in terms of temperature reduction, but also in terms of improving the usability of the school areas by the students.

As a first step, the research team found it necessary to gain a deeper understanding of the study areas by scheduling an inspection of each of them, in collaboration with the municipality's technical offices. This provided a more accurate picture of the condition of the sites and enabled the design drawings to be integrated with detailed information on the surface materials to be used in the climate simulations. In addition, meetings with teachers and school administrators provided a better understanding of how these spaces are used by children on a daily basis, and also brought to light some inconsistencies between the actual uses and the proposed new layouts (e.g., the planting of trees in open areas used for play).

The information gathered was essential to the development of the research.

5 Methodology and Main Research Findings

5.1 Evaluation of Interventions Under *The Green Schools of Lucca* Project in Terms of Effectiveness

The comparison of the microclimatic situations of the school sites before and after the implementation of the planned interventions was carried out using Envi-met, a software widely used for analyses of this type (D'Ambrosio and Leone 2016; Tsoka et al. 2018).

Starting from the geolocation of the study area and the input of climatic data, Envi-met applies computational fluid dynamics models that return its thermal behavior, taking into account the interactions between the different components of the built and open spaces. At the same time, it is possible to derive a measure of thermal comfort expressed by the PMV (Predicted Mean Vote) index, considering the gender, age, height and weight of the users.

The process consists of five steps (Fig. 3).

The first step is to identify the study area. For our purposes, the input data were the geographical coordinates of each school, around which the area to be simulated was defined.

Depending on the size of the schools studied, rectangular simulation grids of 200 to 600 m side were created, divided into cells of 1.5 × 1.5 m, to obtain, at the end of the process, a detailed resolution of the microclimatic variations within the grid in both situations—before and after the works.

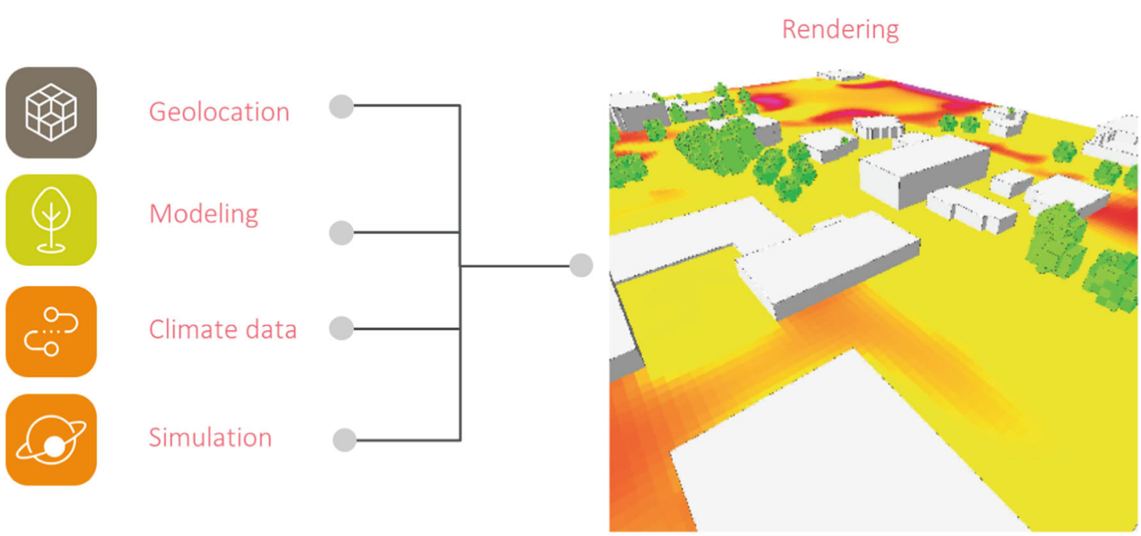

Fig. 3 The five steps of Envi-met's procedure (drawing by Martina Bardini)

An up-to-date orthophoto of each site was then uploaded into Envi-met's "Spaces" workspace, taking care to place the school in the center of the grid, as the software has greater margins of error at the edges. In any case, some of the surrounding urban fabric was included so that the effects of the proposed solutions could be assessed in the immediate vicinity of each school.

Once the reference grid is defined, the second step is to model the elements within it: buildings, soil and surfaces, grass and trees. The difference in vegetation between the pre-existing state and the one envisaged in the climate adaptation project commissioned by the municipality led to the creation of two models to be compared.

Each element was assigned the relevant attributes—i.e., building heights, paving materials and colours, and vegetation characteristics—which, through their ability to absorb or reflect energy fluxes generated by solar radiation or to create shaded areas, interact to determine the thermal behavior of the urban area in question, either exacerbating or helping to mitigate the urban heat island effect.

As far as trees and shrubs are concerned, Envi-met has a specific modeling toolbox ("Albero") that includes a database of the most common species and related attributes in terms of emissivity, leaf density, leaf width and canopy size depending on the age of the plant (young, medium, old). If a species is not listed in the database, it is possible to add it and its attributes manually.

The third step is to enter the climatic data. For the purposes of the research, the minimum and maximum values of the average temperature and the average relative humidity were considered, with reference to the hottest months of the Italian school year (i.e., May and June) in the decade 2013–2022. The data, provided by the "Lucca Orto Botanico" weather station, were obtained from the SIR open access database of the Tuscany Region.[13]

In step 4, the software processes the input data to simulate the temperature trend for a given period of the day. In our case, it was set between 8:00 a.m. and 3:00 p.m., so that when comparing the current state and the project, it would be possible to extract the temperature values corresponding to each open space cell at three times of the school morning (10:00 a.m., 12:00 and 2:00 p.m.). At the end of the data processing, using the Envi-met "Biomet" work window, it is also possible to enter the parameters of a standard user to calculate the corresponding thermal comfort index over the period considered. To display the results of the simulations (step 5), there is a special Envi-met application, "Leonardo", which generates maps and schematic 3D views of the analyzed areas, after setting the colour palettes to visualize the variations of the two indicators considered—temperature and PMV. These are related to the height of a child (1.20 m above the ground) and to the average parameters of a 3-year-old child for preschools and of a 10-year-old child for elementary schools, respectively.

At the end of the process, the values obtained for the ante-operam and post-operam situations of the same area are perfectly comparable, since they are based on the same input data and returned with the same colour scales (Fig. 4). It is worth noting that in order to evaluate the effectiveness of the interventions planned for each school, as well as for the Alcide De Gasperi Park, what is of interest is the delta between the before and after values of air temperature and PMV, which measures the real and perceived temperature reduction attributable to the change, regardless of whether the minimum and maximum temperatures used in the calculations correspond to the most critical climatic conditions recorded in the area.

The simulations carried out show that 10 planned interventions are expected to produce satisfactory temperature reductions (between −0.20 °C and −0.40 °C), while for the others the expected effects are extremely limited (less than −0.05 °C).

5.2 Evaluation of Interventions Under *The Green Schools of Lucca* Project in Terms of Priority

The selection of schools included in the MiTE-funded pilot project was not based on their location in areas relatively more affected by the urban heat island effect, but rather seems to have been inspired by the principle of spreading public resources across different parts of the city.

However, the worsening trend of the climate emergency calls for this approach to be overcome, so that the limited resources available are instead used according to a principle of prioritization, considering the level of risk to the population due to local climatic conditions—or at least preventing them from being directed to the least critical areas of the city.

In this sense, as part of the research, a map of surface temperatures was created and the intervention areas included in the "Green Schools" project were located on it in order to make an ex-post assessment of how critical they actually are in terms of climate. The map, created using the Google Earth Engine platform, shows, through isotherms with assigned colour gradients from light blue to red, the average land surface temperature at 10:00 a.m. recorded by the NASA Landsat-8 satellite over the city of Lucca in the month of May (the same one considered for the simulations with Envi-met) during the five-year period 2018–2022.

[13] http://www.sir.toscana.it/termometria-pub. As for the air velocity, a standard value corresponding to a windless condition (0.2 m/sec) was input.

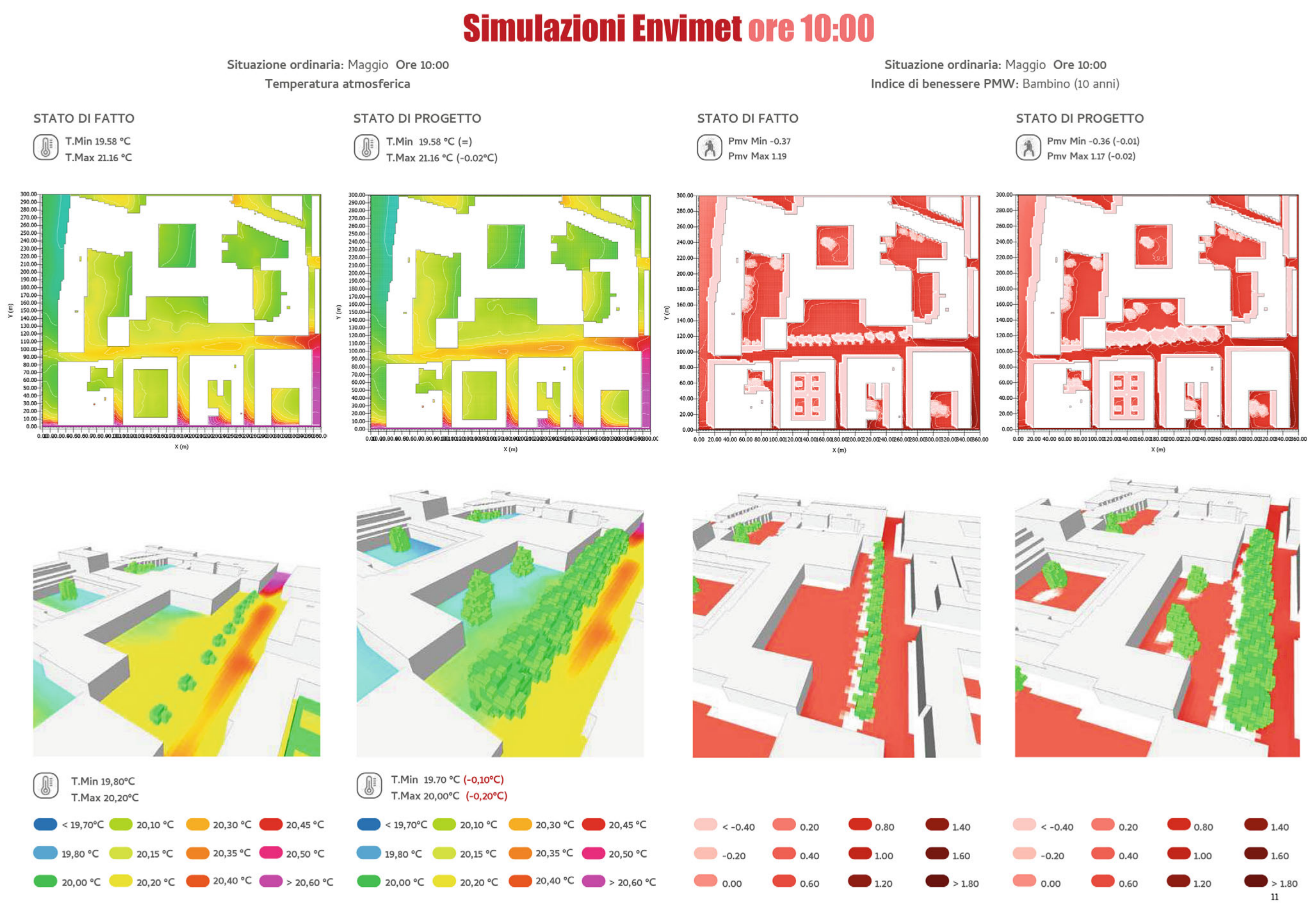

Fig. 4 Comparison of current and project status in one of the 18 school areas analyzed in Lucca—air temperature (left) and PVM index (right) at 10:00 a.m. of an average school day in May

Superimposing the project areas on the map shows that 8 out of 19 (i.e., 8 out of 18 schools) are in urban or peri-urban areas where the average surface temperature is ≤ 22 °C, and therefore do not require interventions to mitigate the urban heat island effect (Fig. 5).

5.3 Analysis and Evaluation Sheets and Survey Reports

The analyses carried out on the project areas have been compiled in a file consisting of as many sheets divided into the following six sections:

1. Spatial framework, showing the location of each project area within the municipal territory and how it fits into the adjacent urban fabric;
2. Planimetry of the project, showing the existing permeable and impermeable surfaces and the planned "green" and "grey" interventions (Fig. 6);
3. Detailed information on the characteristics of the ground and the roofs of the buildings;
4. Current uses of the open spaces, shown on a map and illustrated by the photographs taken during the site visits (Fig. 7);
5. Envi-met simulations, including simulations, both on a 2D and 3D background, of the atmospheric temperature and PVM values of the area concerned in the current and project status; these are carried out, as mentioned, using the average data of a May day at three times of the school hours (10 a.m., 12 and 2 p.m.);
6. Evaluations of the output data, showing the temperature deltas between actual and project conditions resulting from the simulations, both in the project area and its surroundings. As a result, an overall assessment of the effectiveness (high, medium, low) and priority level (high, medium, low) of the planned interventions is given.

Another output of the research, which was not initially planned, is the Survey Report, which was prepared at the

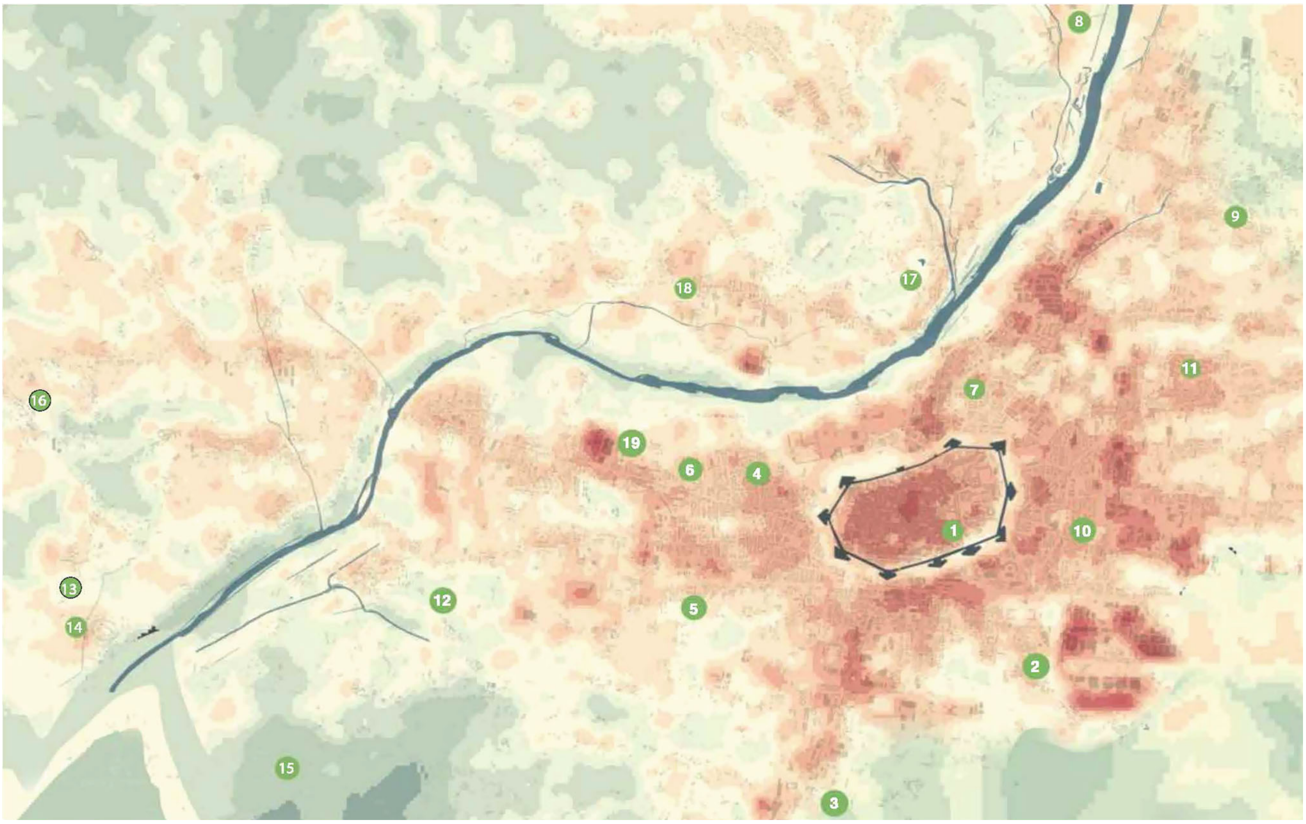

Fig. 5 Location of the “Green Schools of Lucca” project areas on the map of the land surface temperature of the city (average temperature measured in the months of May 2018–2022 at 10.00 a.m. Map processed by Giulia Guerri, CNR Florence; reworked by Martina Bardini)

explicit request of the client to have a record of the information gathered during the visits to the project areas, and in particular to the schools. It contains the problems, wishes and suggestions that emerged during the meetings between the DiDA researcher, the municipal officials present at each visit, and the school operators, which are potentially useful for either integrating or correcting the greening projects delivered to the municipality, in order to get a better use of school open spaces by children.

6 Discussion and Conclusions

The research highlighted the strengths and weaknesses of the pilot project *The Green Schools of Lucca*, which aims to make the city more resilient to the effects of climate change through the greening of open spaces.

The strengths concern, on the one hand, the choice of the outdoor spaces of public preschools and primary schools as prime locations for climate-adaptation-oriented regeneration projects, in line with some innovative experiences carried out in different international contexts. On the other hand, the strengths include the satisfactory results of the climate simulation of the proposed interventions in some areas, which can be taken as a model for future applications; among the options tested, de-paving measures stands out as particularly effective in mitigating high temperatures.

The weaknesses lie in the heterogeneity of the simulation results in the different project areas, which also include interventions that were found to be of little use in increasing urban resilience, either because they are located in parts of the city that do not have particular microclimatic problems, or because the proposed interventions are expected to be ineffective. Both situations can be explained by the lack of a supportive methodology for selecting priority areas for intervention, as well as for design solutions. The study presented here fills this gap by offering an integrated approach to designing smart schools that promote more livable spaces while benefiting from the ecosystem services provided by increased vegetation. In this way, schools can also serve as a testbed and source of inspiration for developing the cities of the future based on assumptions of environmental sustainability and social inclusion.

The key points of this approach can be summarized as follows.

Before focusing on individual projects, it is necessary to consider the location of potential target areas in the urban context and to prioritize interventions according to their

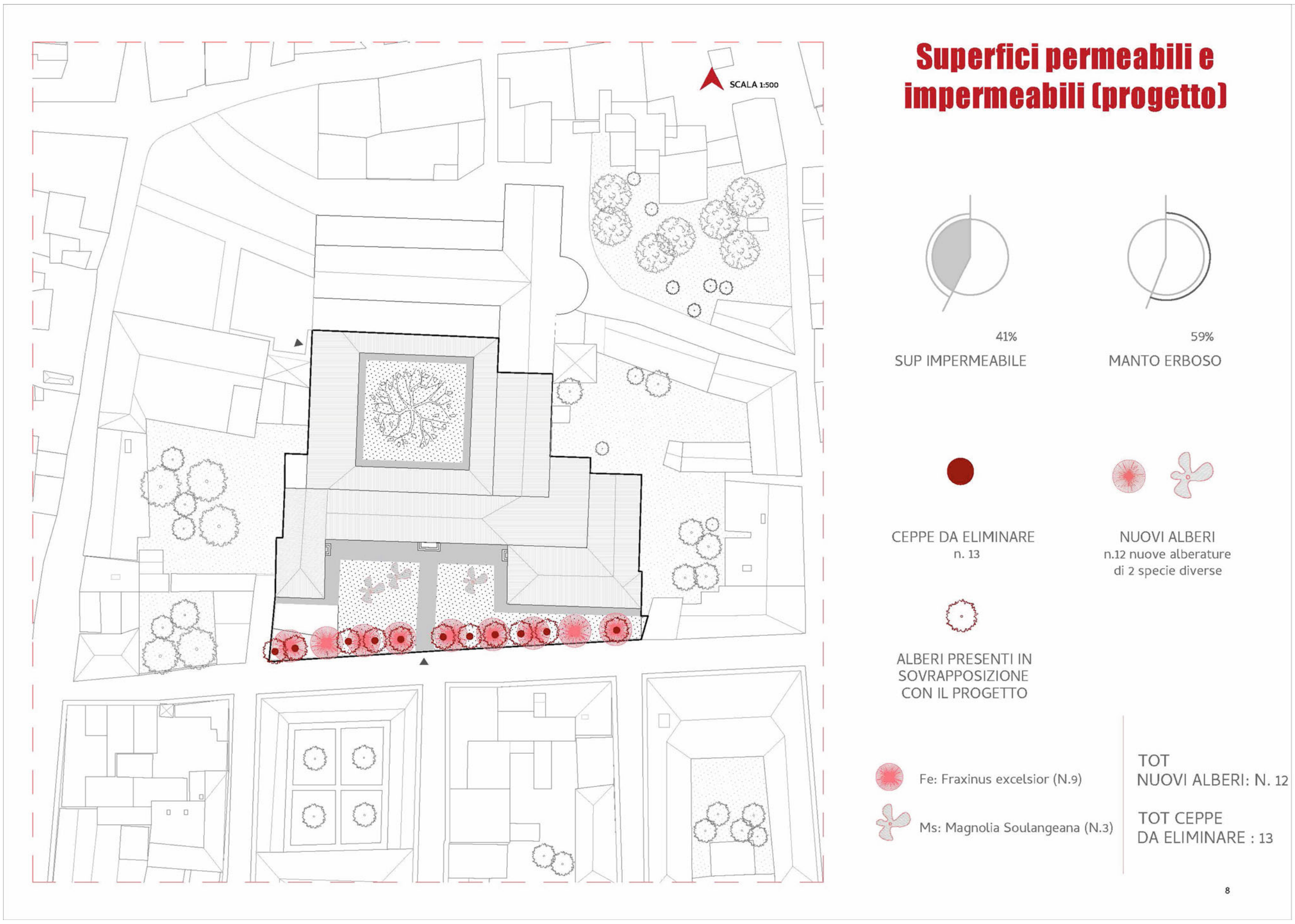

Fig. 6 Redrawn floor plan of the project for the primary school Giovanni Pascoli. In this case, the project involved replacing a row of trees with new, shadier plants (drawing by Martina Bardini)

level of climate vulnerability. The land-surface temperature map, which can be used to overlay the locations of potential intervention areas, can be a useful tool for preliminary assessment of the latter. This does not mean that schools in green peri-urban areas should be excluded from the regeneration program; in fact, even in these cases, it is important to improve the relationship between school spaces and the surrounding environment, for example by introducing appropriately regulated ways of using green spaces outside the school by pupils. It is clear, however, that in allocating resources for greening initiatives, priority should be given to those areas where microclimatic conditions may pose a health risk to users.

Several factors need to be taken into account when redesigning school grounds. On the one hand, climate simulations must be carried out at the same time as the projects are developed, and not afterwards, so that possible alternative solutions (e.g., location and type of plants, creation of green areas, etc.) can be compared and the most effective one selected. On the other hand, interventions to increase the number of trees and green spaces must be considered not only from a climatic-environmental point of view, but also from the point of view of the children who use the school spaces. The Survey Report produced during the research highlighted the importance of discussion among different actors, and in particular the contribution of school operators, in order to respond contextually to different needs and expectations. Other action research initiatives conducted in Tuscany by one of the authors of this paper have shown how the direct involvement of students can be the most effective way to guide design choices, while at the same time representing a formative and public engagement moment of great relevance for the city (Romano et al., forthcoming).[14]

[14] The FIABA project (*Firenze impara ad abitare con gli adolescenti / Florence learns to live with adolescents*), coordinated by Maria Rita Gisotti for DiDA and funded by Fondazione CR Firenze, was carried out in the period 2022–23 and involved two high schools in Florence (Liceo Scientifico Guido Castelnuovo and ITT Marco Polo) in a participatory process for the redesign of school open spaces. The methodology applied brought out the importance of listening to the entire school community in order to define an effective design that is adequate to the needs and expectations of the users.

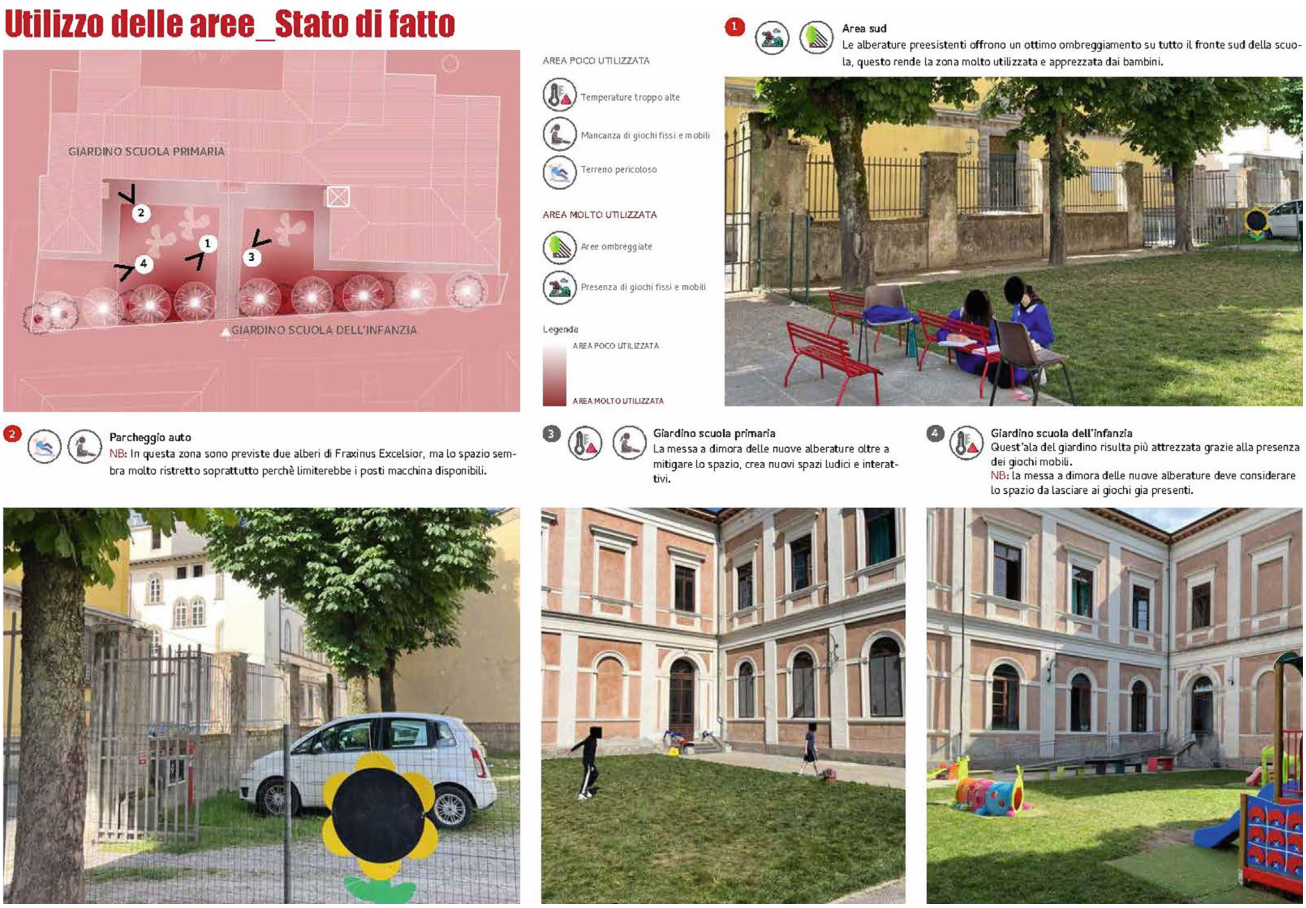

Fig. 7 Current uses of the open spaces of the primary school Giovanni Pascoli. The key map in the upper left shows the intensity of schoolchildren's use of outdoor spaces, with a different colour gradient (drawing and photos by Martina Bardini)

Another recommendation stems from the observation that, given the punctual nature of the interventions envisaged in "*The Green Schools of Lucca*" project and their widespread distribution across the territory, the contribution they can make to reducing temperatures and increasing environmental comfort is inevitably local, with little benefit—as the simulations carried out show—even for the closest urban fabrics.

The greening of school grounds can, however, be the starting point of an integrated system aimed at improving urban resilience through the ecological upgrading of the urban links between one school and another, and between these and other public spaces and facilities, in order to "propagate" the improved effects in terms of environmental well-being to a wider territorial scale. In this sense, the Municipal Green Plan, established in Italy by Law No. 10/2013 "Regulations for the Development of Urban Green Spaces", as a non-mandatory sectoral plan, can be reinterpreted and considered as a strategic framework of interventions on urban nodes and links, to be implemented according to the order of priorities dictated by the climate emergency.

7 Attributions

This paper is the result of a joint reflection by the authors. Sections 1 and 2 were written by Maria Rita Gisotti and Sects. 3, 4, 5, and 6 by Francesco Alberti.

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